The Role of Perceptual Binding in Memory & Awareness

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By

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Abstract

The processes responsible for binding together elements of an experience are known to play a role in guiding behavior across a range of domains within human cognition, including perception, memory, and performance. Broadly speaking, this thesis is concerned with how binding processes might contribute to behavior in another research domain that has received little attention from this perspective, namely, the generation of explicit awareness of statistical relations. More specifically, the primary goal of this thesis was to examine how these binding processes mediate explicit awareness of contingencies between perceptual events, and how this awareness is related to the phenomenological and mnemonic consequences of these binding processes. The empirical work presented in this thesis suggests that awareness of strong statistical regularities is heavily influenced by the relationship between feature bindings across successive visual events, and that mismatches in feature bindings can obscure awareness of these regularities. Furthermore, it was found that binding mismatches likely obscure such awareness by way of their phenomenological and mnemonic consequences. The experimental results from this thesis have important implications for understanding the processes that govern the acquisition of explicit awareness of contingencies, and for theories of visual memory. It is suggested that binding processes may play a role in controlling the coordination between short-term memory representations and ongoing perceptual input.

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PREFACE

This thesis is a 'sandwich'– style thesis, meaning that all three empirical chapters are independent manuscripts that are either published or submitted for publication. Chapters 2 and 3 are published in peer-reviewed journals. The third empirical chapter, Chapter 4, is currently under review at another peer-reviewed journal. For each of these empirical chapters, I am the first author, and my supervisor, Dr. Bruce Milliken, is the second author.

Chapter 2 of this thesis is a reprint of a manuscript that was published in the journal *Consciousness & Cognition*. The reference for this article is as follows: **Fiacconi, C.M., & Milliken, B. (2011). On the role of attention in generating explicit awareness of contingent relations: Evidence from spatial priming. *Consciousness & Cognition, 20,* 1433-1451.** My role in this chapter included experimental design and programming, collecting data, analyzing data, and writing the manuscript.

Chapter 3 of this thesis is a reprint of a manuscript that was published in the journal *Memory & Cognition*. The reference for this article is as follows: **Fiacconi, C.M., & Milliken, B. (2012). Contingency Blindness: location-identity binding mismatches obscure awareness of spatial contingencies and produce profound interference in visual working memory. *Memory & Cognition, 40,* 932-945.** My role in this chapter included experimental design and programming, collecting data, analyzing data, and writing the manuscript.

Chapter 4 of this thesis has been submitted to the journal *Quarterly Journal of Experimental Psychology.* The reference for this article is as follows: **Fiacconi, C.M., & Milliken, B. (submitted). Visual memory for feature bindings: the disruptive effects of responding to new perceptual input. *Quarterly Journal of Experimental Psychology.***

My role in this chapter included experimental design and programming, collecting data, analyzing data, and writing the manuscript.

It should also be mentioned that each empirical chapter was intended to be independent of the others, and therefore, there will be some redundancy with regards to theoretical discussion across these chapters. That said, however, the experiments contained within each chapter are unique and were designed to answer a distinct set of questions. Together, the chapters of this thesis speak to different aspects of a common theoretical issue.

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Table 1. Mean percentage of localization response errors for Experiments 1-4. Error rates are reported as a function of whether the target item in the intervening display overlapped one of the items from the memory array and whether or not a mismatch or a match occurred at the overlapped location. The Location-change heading refers to trials on which participants responded to the location of an intervening display target when that target appeared in a previously unoccupied location. The Mismatch heading refers to trials on which participants responded to the location of an intervening display target that mismatched the previous contents of that location. The Match heading refers to trials on which participants responded to the location of an intervening display target that matched the previous contents of that location

CHAPTER 1: Introduction

A fundamental aspect of human experience is that we perceive and process environmental input in holistic units. When we encounter an object, for example, we experience it not as a bundle of independent features, but as an integrated whole. The idea that we bind together different attributes of our experience into a coherent aggregate is a pervasive theme throughout cognitive psychology, and is a foundational principle in many domains within this discipline. Broadly speaking, this thesis is concerned with this binding process and its contribution to a subset of different human behaviors.

To situate the empirical work presented in this thesis, I will first describe more precisely what the term *binding* entails, as there are many different uses of this term. I will then review the role of binding processes across different sub-disciplines within cognition, including perception, memory, and human performance. The relevant empirical work within each sub-discipline will be emphasized, as well is its contribution to theoretical progress in that domain. Finally, I will outline in detail the specific research questions addressed in this thesis, and illustrate how binding processes could play an important role in the empirical work presented in following chapters of this thesis.

What is Binding?

Simply put, the term *binding* will be used in this thesis to describe the process by which disparate, independent attributes of a percept, event, or experience are integrated together into a unified whole. An important consequence of binding processes is that individual attributes become contextualized – that is, they become associated with other attributes that are temporally co-existent.

The concept of binding first emerged in the perception literature when it was discovered that distinct regions of visual cortex code different perceptual attributes such as color, orientation, form, and motion (Hubel & Weisel, 1962; Hubel & Wiesel, 1977; Livingstone & Hubel, 1988). The question of how the brain integrates the output of each of these modules into a coherent percept is referred to as the *binding problem*. Many theories have been forwarded as solutions to the binding problem, although a general consensus concerning the mechanism of binding has not yet been reached. Nonetheless, feature binding remains an important topic of inquiry in the perceptual domain.

Although the binding problem is rooted in the perception literature, the concept of integrated representations has also been influential in shaping our understanding of human memory. With reference to the human memory literature, the term binding is sometimes used to describe the fact that memory representations are multifaceted – we can recollect not only how the particular events of the September 11th terrorist attacks unfolded, but also where we were, and whom we were with at the time of the attacks. Therefore, a similar binding problem exists with respect to memory. The human brain must somehow conjoin separate aspects of an experienced event together to support the detailed recollection that is characteristic of our mental lives.

Another cognitive domain in which the term binding is often used is human performance. Research in this area is concerned with the processes that allow us to attend and respond to sensory events in the world. The term binding in the context of the performance literature is used in several ways. One use of the term binding in the attention and performance literature refers to the idea that stimuli and their associated responses can be encoded together in memory as an ‘event-file’ (Hommel, 1998). Once encoded, an event-file can then either facilitate or hinder subsequent performance depending on the degree to which subsequent processing demands are congruent with the previously encoded information. Furthermore, binding can also refer to the association between low-level task features such as stimuli/responses, and high-level task features such as task sets or task goals (Mayr & Bryck, 2007; Waszak, Hommel, & Allport, 2003). A consequence of this latter form of binding is that processing a stimulus in one task context can impact subsequent processing of that stimulus in a different task context.

As made clear by the above discussion, binding processes are ubiquitous throughout cognition. The purpose of the next three sections will be to describe in more detail the empirical work on binding processes within perception, memory, and performance.

Binding in Perception

Consider the following scenario: you are presented with the letter X in green and the letter O in blue on a computer screen. According to most models of perceptual processing, the color and form of each letter would be analyzed by independent cell assemblies within visual cortex, thus allowing the brain to represent the colors green and blue, and the letters X and O. It is precisely this form of distributed coding that results in the binding problem: How does the brain know that green belongs with the letter X, and that blue belongs with the letter O?

At the psychological level, one of the first theories to address this concern was proposed by Treisman and Gelade (1980). According to their *feature-integration theory*, individual features are registered pre-attentively in separate feature maps, and are conjoined together to form integrated objects through the allocation of spatial attention. In this model, spatial attention is thought to serve as a 'glue' that binds together features at a particular location in space. One of the empirical cornerstones of this theory stems from the observation of *illusory conjunctions*, which are defined as the incorrect re-combination of individual features into 'illusory' percepts. In a seminal study that demonstrated the striking phenomenology associated with illusory conjunctions, Treisman and Schmidt (1982) presented their participants with a brief display containing three colored letters flanked by two digits presented in black. The task in this experiment was to identify as accurately as possible the two black flanking digits, and then report subsequently any of the other stimuli that were presented. The critical finding from this study was that accurate identification of the digits was accompanied by a high rate of illusory conjunctions concerning the color of the letters presented between the digits. That is, a green X and a blue O was often mistaken to be a blue X and a green O. The authors concluded that dividing attention between the two flanking locations led to impairments in a process that conjoins color and letter codes associated with the unattended letters.

Further evidence for the role of spatial attention in feature binding comes from a study by Prinzmetal, Presti, and Posner (1986). Participants in this study were presented with a target letter X of a particular color (e.g., green) on each trial. Following the presentation of this target item, a spatial cue appeared that signified the likely location at which a set of four letters would appear subsequently. The task was to decide if the target item for that trial was present among the four letters. On trials in which the target item was absent, a subset of trials consisted of a letter set containing each of the features of the target item, but in an incorrect combination (e.g., a blue X among three green O's). On another subset of the target absent trials, the letter set shared only one feature in common with the target item (e.g., a blue X among red Os, or a red X among green Os). The key result was that valid spatial cues reduced the rate of false alarms for letter sets that contained an incorrect conjunction of the target item features, suggesting that the allocation of spatial attention reduced the likelihood of perceiving an illusory conjunction. It should be noted that valid cues also resulted in a somewhat smaller reduction in false alarm rates to letter sets that shared only one feature in common with the target item. Therefore, it seems as though spatial attention plays a role in feature registration in addition to its role in feature binding.

Another empirical pillar of feature-integration theory is the study of visual search. In particular, Treisman and Gelade (1980) demonstrated that search efficiency for target items amongst distractors was highly dependent upon whether the target item was defined by a single feature (green X among red Xs), or by a particular conjunction of features (green X among red Xs and green Os). Indeed, the slope of the function relating the number of display elements to reaction time (RT) for target detection was substantially greater for conjunction search relative to feature search. This result was interpreted as implying that feature search is a parallel, pre-attentive process in which the target item ‘pops-out’ from the search display. In contrast, conjunction search was thought to require the deliberate, serial progression of an attentional spotlight throughout the search display, with attention serving to bind the features of each item, a process necessary during conjunction search but not feature search. Together then, the distinction between feature and conjunction search speaks to the importance of attention in binding features into objects.

Further evidence for feature binding in visual perception comes from studies with neurological patients (Cohen & Rafal, 1991; Estermann, McGlinchey-Berroth, & Milberg, 200; Friedman-Hill, Robertson, & Treisman, 1995; Robertson, 2003; Ward, Danziger, Owen,

& Rafal, 2002). In a particularly dramatic example, Friedman-Hill et al. (1995) tested a patient (R.M.) with bilateral parietal lesions resulting in Balint's Syndrome. Patients with Balint's Syndrome typically exhibit poor spatial awareness resulting in *simultagnosia* – the inability to perceive more than one object at a time. In a simple experiment, the authors presented R.M. with a display containing two colored letters (e.g., a green X and blue O). R.M. was asked to report the identity and color of the first letter that he saw. It was found that even under free viewing conditions and display durations of 10 seconds, R.M. made conjunction errors on up to 38% of trials despite being able to correctly identify the individual features. Furthermore, R.M. was also grossly impaired at reporting the location of one letter relative to the other, a result that highlights his profound deficits in spatial perception. Based on these results, Friedman-Hill et al. (1995) suggested that R.M.'s difficulty in correctly binding features was a consequence of his inability to use location as a reference point for feature binding. Deficits in feature binding have also been observed in hemi-neglect patients with unilateral parietal lesions (Cohen & Rafal, 1991). These patients are typically impaired at orienting attention to the contralesional side of space (Rafal, 1997). As would be predicted by feature-integration theory, hemi-neglect patients ought to produce a high rate of illusory conjunctions relative to feature errors for stimuli presented in their contralesional visual field. Indeed, this prediction was confirmed by Cohen and Rafal (1991).

The feature binding deficits observed with hemi-neglect patients are not limited to illusory conjunctions, and are also found in studies of visual search (Estermann, McGlinchey-Berroth, & Milberg, 2000). This study administered both a conjunction and a feature search task to hemi-neglect patients and healthy controls. Importantly, targets in both types of search task could appear in either the contralesional visual field, or in the ipsilesional visual field. It was found that search slopes for conjunction-defined targets were greater for patients relative to healthy controls only when the target appeared in the contralesional visual field. This result suggests that conjunction search is impaired when the target item appears in a region of space in which attentional orienting is disrupted. This disruption of attentional allocation within the contralesional visual field presumably impairs the proper conjoining of features and therefore results in longer target detection times. Furthermore, search slopes for feature-defined targets were equal for the patients and controls irrespective of the visual field in which the target was presented, suggesting that feature search processes remain relatively intact in the absence of attention. Together, the results from the neuropsychological literature support the idea that spatial attention plays an important role in feature binding, and are generally in agreement with the basic tenets of feature-integration theory.

In sum, the concept of binding has been enormously influential in understanding the processes that govern visual perception. At the psychological level of description, there is a wealth of evidence both from normal participants and neurological patients supporting a role for attention in mediating binding processes. The question of how binding is achieved at the neural level is still a matter of ongoing debate, and several theories have been forwarded including neural synchronization (Singer & Gray, 1995), and pathway coordination (Olshausen, Anderson, & Van Essen, 1993). It will be of considerable interest for future research to determine whether the processes that mediate binding at the neural level can 'scale-up' and merge with the construct of attention at the psychological level.

Binding in Memory

In the previous section, the emphasis was on the role of binding processes in the representation of perceptual information. Although it seems clear that the formation of bound perceptual representations is crucial to veridical apprehension of objects in our environment, one might ask whether such bound representations persist beyond the period of time that these stimuli are present in the environment. In other words, to what extent is feature binding an important component of memory representations?

When referring to the role of binding in human memory, it is possible to distinguish further between binding in short-term memory and binding in long-term memory. Although the terms short-term and long-term memory can be used simply to describe the duration of the interval between the time of encoding and the time of retrieval, these terms are often used to refer to a structural distinction between a short-term memory system and a separate long-term memory system. The issue of whether these two terms should refer only to an encoding/retrieval time scale, or whether they also capture a distinction between memory systems is beyond the scope of this thesis, but it should be noted that most empirical studies on binding processes in short-term memory use this term in a structural sense. Therefore, for the sake of simplicity, when reviewing the literature on binding in short-term memory and long-term memory, I will use these terms to refer to a structural distinction. That said, I remain agnostic with respect to the issue of whether short-term and long-term memory truly represent separate memory systems.

Binding in Short-Term Memory

The vast majority of research conducted on binding processes in short-term memory has focused on the binding of visual features within a sub-system of short-term memory known as *visual working memory* (VWM). This system is thought to be responsible for maintaining online representations of visual information over brief time intervals (e.g., seconds) with the capacity to store 3-4 items simultaneously (Luck & Vogel, 1997). The experimental procedure most often used in studies of VWM is the *change-detection task*. In this task, participants are first presented with a display of items to remember (the memory array). After presentation of the memory array, a blank retention interval (typically ~ 900 ms) occurs and is then followed by the presentation of a test display. On *same* trials, the test display is identical to the memory array. In contrast, on *different* trials, one or more of the items in the test display is not presented in the memory array. The task is simply to indicate whether the memory array and test display on any given trial are the same. Successful performance in this task presumably requires the accurate maintenance of the encoded information, and the ability to compare this information with a subsequent display.

The change-detection task has been used to investigate a number of theoretical questions concerning VWM. One of the primary issues in this literature concerns the representational format of VWM. There is ongoing debate as to whether visual input is stored as a collection of individual features, or as bound feature combinations referred to as objects (Delvenne & Bruyer, 2004; Johnson, Hollingworth, & Luck, 2009; Luck & Vogel, 1997; Saiki, 2003; Vogel, Woodman, & Luck, 2001; Wheeler & Treisman, 2002; Xu, 2002). One of the most influential studies on this topic was published by Luck and Vogel (1997). The authors reasoned that if VWM stores information in an object-based format, then memory accuracy should be limited not by the number of features to be stored, but rather by the number of objects to be remembered. In support of this idea, it was found that change detection accuracy for a set of bi-colored squares was equal to that for a set of single colored squares despite there being twice as many features present in displays containing the former. An important implication of these results is that it suggests that once features are bound together into objects, these objects function as the representational unit in VWM.

Although the findings from Luck and Vogel (1997) were certainly suggestive of object-based storage in VWM, they have proved difficult to replicate (Delvenne & Bruyer, 2004; Wheeler & Treisman, 2002). Wheeler and Treisman (2002) instead proposed that maintaining bound object representations in VWM does not ‘come for free,’ but rather requires focused attention. In their change-detection experiments, it was consistently found that when the test displays contained as many elements as the memory array (whole-display condition), memory for feature bindings was significantly impaired relative to memory for the individual features. In contrast, when the test display contained only a single element (single-probe condition), there was no evidence for a binding specific memory deficit. To explain this pattern of results, the authors suggested that in the whole display condition, attention was required to correctly bind together the features of multiple items in the test display (Treisman & Gelade, 1980), thus diverting attention away from maintaining the initial feature bindings. In contrast, when only a single item appeared in the test display, correctly perceiving this item would presumably require fewer attentional resources than in the whole display condition, and thus leave more resources available to maintain the initial feature bindings.

However, other evidence exists that casts doubt on the view endorsed by Wheeler and Treisman (2002; see also Gajewski & Brockmole, 2006; Johnson, Hollingworth, & Luck, 2009). In a direct test of the hypothesis that attention is required to maintain feature bindings in memory, Johnson et al. (2009) had participants in one group perform a demanding visual search task during the retention interval of a change-detection task. It was reasoned that if attention were required to maintain feature bindings in VWM, then for participants who engaged in visual search during the retention interval, memory for bindings should be worse than memory for features. It was also predicted that no binding-specific memory impairment should be observed for participants who did not engage in visual search during the retention interval. Contrary to this reasoning, the binding-specific impairment was no greater for the participants who performed visual search than those who did not perform visual search during the retention interval.

Overall, it seems as though the evidence for object-based representations in VWM is somewhat mixed. There are some experimental results that clearly favor such a position (Johnson, Luck, & Vogel, 2009; Luck & Vogel, 1997; Vogel, Woodman, & Luck, 2001), although there are other results that at the very least place constraints on this view (Delvenne & Bruyer, 2004; Wheeler & Treisman, 2002; Xu, 2002). More recent research may be beginning to provide us with a resolution to some of these contradictory findings. One possible account for the binding-specific memory deficits observed in the whole display condition of Wheeler and Treisman (2002) is that stored feature bindings are particularly susceptible to overwriting upon onset of the test display (Allen, Baddeley, & Hitch, 2006; Alvarez & Thompson, 2009; Ueno, Allen, Baddeley, Hitch, & Saito, 2011; Ueno, Mate, Allen, Hitch, & Baddeley, 2011). In their test of memory for feature bindings, Wheeler and

Treisman (2002) used test displays in the whole display condition that could either contain all the same features in the same conjunctions as in the memory array (same trials), or contain all the same features but recombined into different conjunctions with respect to the memory array (different trials). Given the perfect overlap in featural content between the memory array and test displays, it is possible that the test display was treated as a 'perceptual update' of the memory array, with this update effectively overwriting the initial feature bindings and rendering them inaccessible. Indeed, this is an idea has been gaining support in the literature (Allen, Baddeley, & Hitch, 2006; Alvarez & Thompson, 2009; Makovski, Sussman, & Jiang, 2008; Makovski, Watson, Koutstaal, & Jiang, 2010; Ueno, Allen, Baddeley, Hitch, & Saito, 2011; Ueno, Mate, Allen, Hitch, & Baddeley, 2011).

In sum, it seems likely that we are able to maintain integrated objects in VWM at least under some circumstances. The emerging theme from this literature is that stored feature bindings are 'fragile' and readily disrupted by subsequent perceptual input. An important research endeavor in this field will be to refine our understanding of how we coordinate information stored in memory with incoming sensory data.

Binding in Long-Term Memory

The contribution of binding processes to human memory is not limited to studies of short-term memory. Indeed binding processes have been central in explaining memory performance over longer time scales (e.g., minutes, days, and years) as well. Memory over these time scales is typically thought to be the province of a long-term memory (LTM) system that encompasses our knowledge of facts about the world, as well as individual experiences.

The importance of binding processes in long-term memory is evidenced by the fact that bound representations are at the core of one of the most influential concepts in memory research. In 1972, Endel Tulving proposed a distinction between *semantic memory* and *episodic memory*. Semantic memory refers to a memory system that stores facts, names, and other forms of general knowledge. Episodic memory, on the other hand, refers to a memory system that allows us to retrieve and recollect specific prior experiences. The episodic memory system, then, is said to store bound representations that contain not only a focal event, but also the contextual details associated with that event, such as the time and place in which it occurred.

One source of evidence for binding in episodic memory stems from studies of free-recall. In a typical free-recall task, participants are given a list of words to study, and then following some retention interval they are asked to recall as many of the words from that list as they can. Kahana and colleagues (Howard, Youker, & Venkatadass, 2008; Kahana, 1996; Sederberg, Howard & Kahana, 2008;) demonstrated that after recalling a given item from a list, there was a greater probability that the next word recalled would be from a serial position that was temporally adjacent to the previously recalled item. This effect, known as the *lag-recency effect*, suggests that each list item is represented in memory together with the temporal context in which it first appeared. Retrieval of an item along with its temporal context can then be used as a retrieval cue to guide subsequent recall (Howard & Kahana, 2002).

Interestingly, bound representations within long-term memory can also be accessed implicitly without awareness on the part of the rememberer (Chun & Jiang, 1998; Ryan, Althoff, Whitlow, & Cohen, 2000). In a clever series of experiments, Ryan et al. (2000) had participants view a series of scenes while monitoring their eye movements. Some scenes were repeated intact throughout the experiment, while others underwent a slight manipulation between the initial presentation and the final presentation. For the manipulated scenes, the relation between some of the elements within the scene was changed, and the location within the scene at which this manipulation was applied was termed the *critical region*. The key comparison in these experiments was the fixation patterns obtained for a given scene when it was repeated intact relative to when its subsequent presentation contained a relational manipulation. It was found that the proportion of fixations into the critical region when a manipulation had taken place was greater than the proportion of fixations into that region when no manipulation had taken place. These results imply that upon initial viewing of the scene, the relations between elements within that scene were bound together and encoded into memory. What is particularly noteworthy here is that some participants showed this effect in the absence of any explicit awareness of the scene manipulation.

Ryan et al. (2000) also administered this experimental procedure to amnesic patients to investigate whether such patients are capable of forming bound representations. In contrast to healthy controls, amnesic patients did not exhibit a greater proportion of fixations toward the critical region in the presence of a manipulation. These results led the authors to propose that one of the primary deficits in amnesia is the inability to represent relationships between distinct parts of an event, or, in other words, to form bound representations.

As suggested by the empirical results described in this section, the binding together of distinct attributes of an event appears to be an integral property of episodic memory representations. Such representations support the recollection of prior episodes in their entirety, and can also guide our behavior implicitly. In sum, the concept of bound representations is a foundational principle that continues to be a core theme in human memory research.

Binding in Human Performance

Research in the human performance domain is primarily concerned with understanding the processes that support our ability to attend and respond efficiently to sensory input. In contrast to the perception and memory literatures, interest in the contribution of binding processes to human performance is relatively recent. Indeed, a common assumption in many attention and performance tasks is that behavior is driven primarily by activation states of abstract memory representations and task sets (Lee, Mozer, & Vecera, 2009; Malkjovic & Nakayama, 1994; Mayr & Keele, 2000; Morton, 1969; Rogers & Monsell; Tipper, 1985; Tipper & Cranston, 1985; Tipper, Brehaut, & Driver, 1990). These abstract representations presumably do not code idiosyncratic bindings between features of an experience, but instead capture the stable aspects of an experience that do not change from one context to the next. A common assumption in attention and performance tasks is that these representations become activated temporarily when perceiving and/or responding to stimuli. Furthermore, this activation can persist for a short period of time and influence performance for a following stimulus that requires access to this same or related representations.

Although abstractionist accounts of performance predominated in the early studies of quite a few attention and performance phenomena, in all cases there has followed a period of interest in the contribution of bound episodic representations to behavior (Allport, Styles, & Wylie, 2000; Hommel, 1998; Huang, Holcombe, & Pashler, 2004; Kahneman, Treisman, &

Gibbs, 1992; Mayr & Bryck, 2007; Park & Kanwisher, 1994; Spape & Hommel, 2008; Thomson & Milliken, in press; Waszak, Hommel, & Allport, 2003; Wilson, Castel, & Pratt, 2006). From this alternative perspective, behavior in performance tasks is driven not by the activation/inhibition of abstract representations, but rather by the retrieval of bound memory traces that contain information regarding the stimulus and the context in which it was encountered.

One of the first demonstrations that bound representations could play a role in human performance came from a landmark study by Kahneman and colleagues (Kahneman, Treisman, & Gibbs, 1992). Participants were presented first with a preview display in which several letters appeared briefly in different screen locations demarcated by placeholders. Following a brief delay, a target display was presented that contained a single letter appearing in one of the previously demarcated locations. The dependent measure of interest in this task was the RT to name the identity of the letter in the test display. The critical finding from this experiment was that participants were faster to name the identity of the target letter when that letter appeared in the same location as in the preview display (same-object condition) relative to when it appeared in the location of a different letter (different-object condition). This result is consistent with the idea that participants formed a bound memory representation of each letter in a particular spatial location in the preview display. Kahneman et al (1992) referred to these bound representations as ‘object-files.’ To explain the effect described above, Kahneman et al. suggested that the onset of a particular target in the test display cues the retrieval of an object-file that shared the same spatio-temporal coordinates. Performance is then facilitated to the extent that there is a good match between the featural content of the retrieved object-file and the new perceptual target. In this way, Kahneman et al. argued that online performance can be guided by the retrieval of bound memory representations.

Hommel (1998) expanded the concept of object-files by suggesting that, in addition to stimulus features, the memory representations that guide performance can also contain response-related information. To highlight the inclusion of response-related information, Hommel (1998) re-named these memory representations 'event-files.' In a compelling series of experiments, Hommel (1998) demonstrated that repeating stimulus features across successive displays only benefited performance when the response to that stimulus was also repeated. This result implies that particular response features associated with a given stimulus are encoded into memory alongside the perceptual features of that stimulus. In turn, performance is facilitated only when there is a good match in terms of both the stimulus and response features between two successive events. In contrast, performance is particularly poor when there exists a partial-match between the stimulus and response features between two successive events. This relatively simple event file integration principle holds substantial explanatory power in the attention and performance literature. The following two sections offer an illustration of the utility of this principle in two particular attention and performance domains.

Binding and Negative Priming

One of the primary goals of research on human performance is to understand how we select information for subsequent processing from the constant stream of perceptual input. One phenomenon that has received extensive study for this purpose is negative priming (Milliken, Tipper, & Weaver, 1994; Milliken, Tipper, Houghton, & Lupianez, 2000; Neill &

Mathis, 1998; Neill, Valdes, Terry, & Gorfein, 1992; Park & Kanwisher, 1994; Shapiro & Loughlin, 1993; Tipper, 1985; Tipper & Cranston, 1985; Tipper, Brehaut, & Driver, 1990; Tipper, Weaver, & Houghton, 1994; Tipper, Weaver, & Milliken, 1995). In the spatial variant of the negative priming task, participants are presented with a prime and a probe display that contain a target (e.g., the letter O) and a distractor (e.g., the letter X). The task is simply to respond to the location at which the target letter appears in both displays. The critical finding is that response to the target letter in the probe display is slowed when it appears in the location at which the prime distractor appeared, relative to a condition in which the probe target appears in a previously unoccupied location. This result has been termed *spatial negative priming*. The initial explanation forwarded by Tipper and colleagues (Tipper, Brehaut, & Driver, 1990; Tipper, Weaver, & Houghton, 1994) to account for this result was the distractor inhibition hypothesis. By this view, in order to select and respond to the target location in the prime display, participants must inhibit or suppress the representation of the distractor location. Slowed responses to probe targets that appear in this previously ignored location are a consequence of having to overcome the initial suppression that was directed toward this location.

Although initially attractive, a number of subsequent results have been difficult to accommodate within this framework. In particular, Park and Kanwisher (1994) presented participants with a prime display that contained two distracter letters without a target present. According to the distractor inhibition hypothesis, the absence of a target item in the prime display negates the requirement to suppress the distractor location, and consequently no spatial negative priming should be observed in this condition. In contrast to this prediction, Park and Kanwisher found slowed responses to the probe target when it appeared in the same location as one of the previous prime distractors. To account for these results, Park and Kanwisher proposed a mismatch hypothesis, whereby spatial negative priming was the result of a location-specific perceptual mismatch between the prime distractor (X) and the probe target (O).

The mismatch hypothesis forwarded by Park and Kanwisher (1994) is consistent with the theme outlined above, that bound episodic representations can contribute to behaviour in the attention and performance domain. Indeed, the mismatch hypothesis is closely related to the object-file framework developed by Kahneman and colleagues (Kahneman, Treisman, & Gibbs, 1992). When a probe target (e.g., the letter O) appears in the same location as prior distractor (e.g., the letter X), we can presume that it cues the retrieval of the object-file associated with this prior distractor. The poor match between the location-identity binding inherent to the retrieved object-file (e.g., X in top location) and the location-identity binding of the current probe target (e.g., O in top location) then results in slowed performance.

Negative priming, then, constitutes one example of how binding processes can contribute to performance tasks in which behavior was traditionally thought to be driven by the activation/inhibition of abstract memory representations (e.g., distractor inhibition).

Binding and Task-Switching

Cognitive control refers to those processes that help guide our actions in accord with current goals and intentions. One empirical paradigm commonly used to study these processes is task-switching (Allport, Styles, & Hsieh, 1994; Allport & Wylie, 2000; Jersild, 1927; Mayr & Bryck, 2005, 2007; Rogers & Monsell, 1995; Waszak, Hommel, & Allport, 2003). Empirical studies employing the task-switching paradigm have consistently demonstrated a cost associated with switching between two tasks relative to repeating the same task – an effect known as a 'switch cost.' Switch costs were initially thought to reflect the time needed to re-configure an executive control mechanism to prepare for a change in task. By this view, preparing for an upcoming task switch requires the suppression of the already active competing task set.

More recently however, it has been proposed that such costs may reflect discrepancies in the bindings between particular stimuli and the task context in which they were initially encountered (Allport & Wylie, 2000; Waszak, Hommel, & Allport, 2003). A particularly compelling demonstration of this idea is found in a study by Waszak et al. (2003). In their experiments, participants were given overlapping picture-word stimuli, and were instructed on each trial either to read the word, or name the object depicted in the picture. Critically, one set of picture-word stimuli appeared only in the word reading task, another set appeared only in the picture naming task, and a final set could appear in both tasks. The key finding from these experiments was that switch costs were larger for picture-word stimuli that appeared in both tasks relative to those stimuli that appeared in only one of the two tasks. Moreover, it was shown that this effect lasted across many trials, suggesting a role for memory in producing this effect. To interpret these results, Waszak et al. (2003) argued that each stimulus is encoded into memory bound together with the task context in which it was encountered. Therefore, perceiving the stimulus again should retrieve the response and task-related information associated with it. By this logic, switch costs are a result of interference from stimulus-based learning processes associated with the competing task context.

Like negative priming, task switching represents another instance of how binding processes contribute to performance tasks once thought to measure abstract activation states. The emerging theme from the performance literature, then, is that bound memory representations can guide behavior when we act and perform in the world around us. Of considerable interest in the future will be to understand how binding processes interact with other cognitive mechanisms to shape behavior in this domain.

Overview of Empirical Work

Although significant progress has been made in understanding the role of binding processes in human performance, a number of questions remain. An important, yet often overlooked aspect of performance tasks is the nature of the accompanying phenomenology. The paucity of research on this topic is somewhat surprising given that phenomenological awareness of stimulus properties and/or task structure can be an important determinant of behavior across a wide range of experimental tasks (Cheesman & Merikle, 1986; Debner & Jacoby, 1994; Eimer & Schlaghecken, 2002; Jimenez, Vaquero, & Lupianez, 2006; Vaquero, Fiacconi & Milliken, 2010). Correspondingly, understanding the factors that mediate such phenomenological awareness will be of importance if we are to fully explain behavior in human performance tasks.

Broadly speaking, this thesis examines how bound representations influence the ability to acquire explicit awareness of statistical regularities in a performance context, and how this type of awareness depends upon the phenomenological and mnemonic consequences of binding mismatches across successive events. The focus of Chapter 2 is a surprising observation reported in a paper published prior to the outset of this thesis, in which participants were unable to verbalize a very strong trial-to-trial statistical regularity (Vaquero, Fiacconi, & Milliken, 2010). The goal of the research described in Chapter 2 was to assess the role of attention in generating awareness of such regularities. The results from the experiments suggest that the role of attention is somewhat minimal, and that awareness is primarily governed by the relationship between stimulus bindings across successive events. Chapter 3 aims to test the hypothesis that mismatches in stimulus bindings across successive events can produce mnemonic impairments that impact the acquisition of explicit awareness of statistical regularities. Indeed, I found strong evidence to suggest that awareness of these regularities is related to the mnemonic consequences associated with binding mismatches. Finally, the focus of Chapter 4 was to examine in more detail the processes that underlie the mnemonic deficits associated with binding mismatches. I consistently found that executing a response toward a stimulus whose features mismatch that of a prior stimulus severely disrupts memory performance for the feature bindings associated with that initial stimulus.

CHAPTER 2: On the Role of Attention in Generating Explicit Awareness of Contingent Relations: Evidence from Spatial Priming

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PREFACE

The experiments conducted in Chapter 2 stemmed from an interesting set of results reported by Vaquero et al. (2010). In their study, participants were exposed to a strong statistical regularity whereby the location of a target item in the second of two successive visual displays was predicted by the location of a preceding item in the first of these displays with 75% validity. Remarkably, almost all of the participants in this task failed to correctly verbalize this predictive relation when the target item mismatched the identity of the preceding predictive item. In contrast, when the identities of these two items were the same, nearly all participants were able to correctly verbalize this relation. To account for this result, the authors suggested that poor awareness of the contingency defined by identity mismatches was a consequence of inattention to the predictive item in the first display. However, the evidence supporting this assertion was indirect. Chapter 2 aimed to provide a more direct test of the inattention hypothesis by requiring participants to directly attend to the predictive item in the first display. If participants' awareness of the contingency was obscured by inattention, then requiring participants to attend to the critical item ought to increase the observed levels of contingency awareness. In contrast, if awareness of this contingency were primarily mediated by factors other than inattention, requiring participants to attend to the critical item ought to have little effect on contingency awareness. The results reported in Chapter 2 support the latter hypothesis, and constitute the first piece of evidence that bottom-up event integration processes play a key role in mediating awareness of strong statistical regularities between successive visual displays.

Abstract

In a series of four experiments, we examine the hypothesis that selective attention is crucial for the generation of conscious knowledge of contingency information. We investigated this question using a spatial priming task in which participants were required to localize a target letter in a probe display. In Experiment 1, participants kept track of the frequency with which the predictive letter in the prime appeared in various locations. This manipulation had a negligible impact on contingency awareness. Subsequent experiments requiring participants to attend to features (color, location) of the predictive letter increased contingency awareness somewhat, but there remained a large proportion of individuals who remained unaware of the strong contingency. Together the results of our experiments suggest that the construct of attention does not fully capture the processes that lead to contingency awareness, and suggest a critical role for bottom-up feature integration in explicit contingency learning.

Introduction

The idea that unconsciously processed stimuli can impact behavior has been a contentious one for many years (Holender, 1986; Eriksen, 1960; Merikle & Reingold, 1992; Reingold & Merikle, 1988; Cheesman & Merikle, 1986; Merikle, Smilek, & Eastwood, 2001; Marcel, 1983). In some demonstrations of unconscious influences on behavior, awareness has been manipulated with masked priming methods. In these studies, the experimenter is often interested in demonstrating a dissociation between participants' awareness of a masked prime and the influence of that masked prime on behavior. For example, Marcel (1983) reported that participants were capable of extracting semantic information from a masked prime despite being unable to accurately detect its presence.

Yet, there are other methods in which perception is not limited using a masking method, and in which stimuli present for relatively long durations appear not to be consciously perceived (Mack & Rock, 1998). For example, people are often unable to report the appearance of unmasked stimuli when their attention is directed elsewhere (Mack & Rock, 1998; Most, Scholl, Clifford, & Simons, 2005; Simons & Rensink, 2005). These studies support the idea that attention is intimately related to conscious perception (Merikle & Joordens, 1997; Most, Scholl, Clifford, & Simons, 2005). However the precision of the coupling between attention and conscious perception remains a debated issue (Koch & Tsuchiya, 2006). Whereas some studies point to a very close coupling (Merikle & Joordens, 1997), other studies have highlighted a divergence between these two constructs (Koch & Tsuchiya, 2006; Lamme, 2003; Kentridge, Heywood, & Weiskrantz, 2004).

Our goal in this paper is to examine the relation between attention and consciousness in light of a finding that we reported recently elsewhere (Vaquero, Fiacconi & Milliken, 2010). In this prior study, we found that qualitatively different patterns of performance in a spatial localization task were associated with different subjective reports of awareness of contingencies between prime and target events. There was no masking procedure used to preclude awareness of primes, and it seemed reasonable that attention to the prime and target events may have mediated awareness of prime-target contingencies. To this point, however, this issue has not been tested directly. We describe four experiments here that did address this issue. Prior to describing these experiments, a brief review of the relevant literature is provided.

The Dissociation and Qualitative Difference Methods

Many investigations into the distinction between conscious and unconscious processes have relied on the *dissociation method* to demonstrate the existence of unconscious processes. The basic logic underlying such experiments is that if it can be shown that an exhaustive measure of conscious processes exhibits null sensitivity to some perceptual information, and yet that same perceptual information can be shown to impact performance in some other task, then the existence of unconscious perceptual processes can be inferred. This method has been used in quite a few contemporary studies of unconscious perception (e.g., Marcel, 1983; Fowler, Wolford, Slade, & Tassinary, 1981; see also Sidis, 1898). Although at first blush such results may seem convincing, critics have rightly questioned whether self-report provides an exhaustive measure of conscious processes (Holender, 1986). Indeed, Nisbett and Wilson (1977) have argued that self-reports may reflect, at least in part, participants' theories of how perceptual experience relates to behavior. As such, it seems unlikely that wide agreement could ever be achieved regarding any particular measure being exclusive to conscious processes. Without establishing this exclusivity, it is impossible to convincingly demonstrate the existence of unconscious processes using the dissociation method (Reingold & Merikle, 1990; Holender, 1986; Merikle & Reingold, 1992).

An alternative approach to studying unconscious processing that does not hinge on an exclusivity assumption is known as the *qualitative difference* method (Cheesman and Merikle, 1986). By this method, the existence of unconscious processing can be inferred whenever it can be shown that perception of a stimulus can have *qualitatively* different effects on behavior as a function of subjectively reported awareness of that stimulus. For example, Cheesman and Merikle used a modified Stroop task in which participants were to name the color of a color patch that appeared following the presentation of a sub-threshold or supra-threshold color word prime. Thresholds of awareness were determined prior to the test session on the basis of subjective report of participants. In one condition, 33% of the color patches were congruent with respect to the preceding color word, while in the other condition 66% of trials were congruent. It was found that the size of the Stroop effect was not sensitive to the proportion manipulation when sub-threshold primes preceded the color patch. However, when supra-threshold primes were used, the Stroop effect was larger for the high proportion congruent condition than for the low proportion congruent condition, suggesting that participants strategically used the prime to predict the color of the color patch when the proportion of congruent trials was .66. This experiment nicely demonstrates the qualitative difference method. The effect of the proportion congruency manipulation on the size of the Stroop effect was qualitatively different as a function of awareness of the prime stimulus. This and other similar demonstrations (Eimer & Schlaghecken, 2002; Jimenez, Vaquero, & Lupianez, 2006, Merikle, Smilek, & Eastwood, 2001, Frings & Wentura, 2005) have lent strong support for the existence of unconscious perceptual processesing.

Attention As A Mediator of Conscious Awareness

As mentioned above, although many studies of unconscious perceptual processing have relied on visual masking procedures, there has been increasing interest in procedures that can measure unconscious perceptual processing without the drawbacks associated with masking techniques. Indeed, the ecological validity of visual masking research can be questioned on the grounds that life rarely presents us with a 50 ms glimpse of meaningful visual information that is then overwritten by meaningless visual information. A more ecologically valid context in which unconscious perceptual processing might be measurable occurs when a clearly visible perceptual event is not perceived, reported, or remembered consciously as a result of it not being the focus of attention.

An interesting phenomenon that speaks directly to this issue has come to be known as *inattentional blindness* (Mack & Rock, 1998). Inattentional blindness occurs when observers fail to report a fairly obvious stimulus if attention is directed elsewhere within a display. Demonstrations of this phenomenon can be quite striking. In the classic paradigm, observers are asked to indicate which arm of a large cross is longer (vertical or horizontal). On some trials, a small colored square is presented simultaneously in one of the four quadrants created by the cross. Surprisingly, about one-quarter of participants fail to notice the colored square. When the cross appears off in the periphery and the square appears at fixation, the effect is even more dramatic, with three-quarters of participants failing to notice the colored square.

In another compelling demonstration of inattentional blindness, Simons and Chabris (1999) asked participants to watch a video of a group of people passing a basketball back and forth. Participants were to count the number of passes that were made. During the video, a man dressed in a gorilla suit traversed the screen and was visible for five seconds. Simons and Chabris found that nearly three-quarters of the participants failed to notice the gorilla! Together, these experiments suggest that attention plays a crucial role in conscious perception (see also Merikle & Joordens, 1997). Apparently, not all information impinging upon the retina is consciously perceived. In fact, when attention is directed toward a given region of space, people may become functionally blind to stimuli appearing in other regions of space.

Much of the research on the relation between attention and awareness has been concerned with how attention might influence the conscious perception of a single stimulus presented at one moment in time. An additional issue worthy of study concerns how attention might influence conscious awareness of *relations* between stimuli occurring at distinct points in time. Research in this area has traditionally been the domain of investigators interested in contingency or associative learning. Yet, as pointed out by numerous researchers (De Houwer, Vandorpe, & Beckers, 2003; Brewer, 1974; Lovibond, & Shanks, 2002), models of associative learning have largely neglected the role of conscious, strategic processes. There is mounting evidence that higher level cognitive factors are important contributors to contingency learning (De Houwer, Vandorpe, & Beckers, 2005; De Houwer, Beckers, & Vandorpe, 2005; Colgan, 1970). Colgan (1970) found that conditioned GSRs (galvanic skin responses) were highly influenced by participants' beliefs about the relationship between the CS (conditioned stimulus) and the US (unconditioned stimulus). Specifically, when participants were informed that a tone previously paired with a shock would no longer signal an upcoming noxious event, participants showed significantly reduced GSRs in response to the tone. Indeed, Lovibond and Shanks (2002) conclude in their review that the bulk of available evidence suggests that conditioned responses (CR) occur only in the presence of conscious awareness of the CS-US contingency. Thus it seems as though some forms of associative learning are cognitively mediated. Given that such learning may depend on awareness, the question of how this awareness arises and its potential relationship to attention is an important one.

Contingency 'Blindness' in Spatial Priming

A recent study that documented a profound 'blindness' to a strong contingency between events offered the present opportunity to study this issue (Vaquero, Fiacconi, & Milliken, 2010). Vaquero et al. investigated the role of conscious and unconscious processes in performance of a spatial localization task. In their task, subjects were presented with a prime and probe display as shown in Figure 1. The prime and probe display consisted of an X and an O presented in two of the four boxes in each of the displays. The participant's task was simply to locate the target O in the probe display. Prior studies using this type of procedure have revealed two different processes that contribute to performance.

One of these processes was revealed in a study reported by Park and Kanwisher (1994). This study demonstrated that feature mismatches occurring at the location of the probe target can produce a strong influence on performance. Specifically, response times to the probe target (O) are often slow when this target re-appears in a location that was previously occupied by mismatching prime letter (X), relative to when the probe target appears at a previously unoccupied location. In contrast, response times to the probe target (O) are often relatively fast when it appears in the location that was previously occupied by a matching prime letter (O). These results are consistent with the object-file updating framework forwarded by Kahneman, Treisman, and Gibbs (1992). This framework proposes that features of an object are integrated together with an object's location into a temporary episodic ‘object-file.’ When the visual system receives subsequent input, a rapid correspondence process determines whether the previously established object-file should be updated with the contents of the new input, or a new object-file must be created. Object file updating is thought to occur when the spatio-temporal co-ordinates of the current input correspond with those of an existing object file, and the speed of the updating process then depends on the match between the features of the current input and those encoded in the object file. The different speeds of object file updating then provides a nice account for the Park and Kanwisher results described above..

A second process thought to impact performance in this task is related to inhibition of return (IOR) effects commonly observed in spatial cueing tasks (Posner & Cohen, 1984). Put simply, IOR refers to the finding that responses to targets appearing in previously occupied locations are slowed relative to targets that appear at previously unoccupied locations. The role of an IOR-like process in tasks that involve spatial localization is implicated most clearly in prior studies in which responses were slow when a probe target appeared in a previously occupied location irrespective of the match/mismatch of the preceding letter (Christie & Klein, 2001; Milliken, Tipper, Houghton, & Lupianez, 2000; Vaquero et al., .2010)

The primary motivation for the Vaquero et al. (2010) study was to examine how awareness and conscious strategies mediate the contribution of these two processes to performance. In Experiment 1 of their paper, on 75% of the experimental trials the O in the probe display appeared where the X had appeared in the prime display. These trials were known as Location-repeat/Identity-mismatch trials. The remaining trials were split between two conditions: Location-change trials where there were no location repetitions between prime and probe, and Location-repeat/Identity-match trials in which the probe O appeared in the same location as the prime O. Subjects were instructed to respond by moving a joystick toward the location of the probe O. Following the completion of experimental trials, subjects were given a brief questionnaire that was designed to assess a) whether participants were aware of the high proportion of Location-repeat/Identity-mismatch trials, and b) whether they strategically used the contingency to localize the probe O. Remarkably, only 2 of 14 participants noticed the high proportion of Location-repeat/Identity-mismatch trials, and probe RTs were *slower* on both the Location-repeat/Identity-mismatch and Location-repeat/Identity-match trials relative to the Location-change trials.

Experiment 2 was identical to Experiment 1 with the exception that the percentage of Location-repeat/Identity-match trials rather than Location-repeated/Identity-mismatch trials was 75%. Here, 11 of 12 participants were aware of the strong contingency, and performance was fastest for the Location-repeat/Identity-match trials, and slowest for the Location-repeat/Identity-mismatch trials, a pattern of results consistent with the object-updating framework of Kahneman et al. (1992).

The vastly different results in Experiments 1 and 2 led the authors to propose a potential link between where attention was allocated in the prime, and the resulting awareness of prime-probe contingencies. In particular, they suggested that the consistent requirement to respond to the probe O may have resulted in attention shifting involuntarily to the prime O and not to the prime X. In Experiment 1, this involuntary shift of attention to the prime O would have directed attention away from the critical prime item on which the contingency was based (i.e., the X), whereas in Experiment 2 such a shift of attention would have directed attention toward the critical prime item on which the contingency was based (i.e., O).

To test this hypothesis, the authors conducted an additional experiment (Experiment 3) in which the O was removed from the prime display. If attention had been captured by the prime O in the prior experiment, and if it was this capture by the prime O that prevented participants from becoming aware of the strong contingency involving the prime X, then removal of the prime O ought to raise awareness of the contingency in this experiment. Indeed, approximately half of the participants reported awareness of the critical contingency involving the prime X in this experiment. Interestingly, participants who expressed awareness of this contingency responded *faster* on Location-repeat/Identity-mismatch trials than on Location-change trials, whereas participants who were unaware of the contingency responded *slower* on Location-repeat/Identity-mismatch trials than on Location-change trials. In other words, a qualitative difference finding was observed – trial type had a qualitatively different effect on RTs depending on whether subjects were aware or unaware of the contingency.

Current Experiments

The research described above offers some modest, indirect support for the following pair of ideas. First, attention to an above threshold prime event can facilitate awareness of a strong prime-probe contingency. Second, awareness of a prime-probe contingency can lead participants to strategically modulate object-updating processes (Kahneman et al., 1992). The present experiments were designed to examine the first of these two ideas more directly, as well as to investigate the conditions under which contingency awareness is predictive of behavioral performance. The basic procedure for all of the experiments reported here mirrors Experiment 1 in Vaquero et al. (2010). However, across the experiments we introduce a series of manipulations designed to influence attention to the predictive prime stimulus.

Given the findings of Vaquero et al., our straightforward hypothesis entering this study was that such attention manipulations ought be very effective in controlling awareness of contingencies between prime and probe stimuli. We report the effectiveness of these attention manipulations and speculate as to the underlying processes responsible for producing awareness, and for modulating the relations among awareness, strategy, and behavior.

Experiment 1

In Experiment 1 of the Vaquero et al. (2010) study, the probe target O appeared in the same location as a preceding X on 75% of trials, and yet only two of 14 participants estimated that these trials occurred more than 50% of the time. Vaquero et al. suggested that this level of unawareness may have been the result of participants not attending to the prime X, and instead attending to a prime O in a different location. If inattention to the prime X was responsible for this finding, then giving subjects a task that requires selective processing of the prime X should change the results markedly. In a first attempt to examine this proposal, we used the same task as in Experiment 1 of the Vaquero et al. study, with the additional requirement that participants were to keep a running tally of the number of times the prime X appeared in either the top or bottom location during a block of trials. The rationale here is that by forcing participants to selectively process the prime X, the distracting effects of the prime O ought to be minimal, and thus participants ought to become aware of the strong contingency between prime X and probe O.

Method

Participants. Sixteen undergraduate students from an introductory psychology course at McMaster University participated in exchange for course credit. The mean age of participants was 18.2 years. All participants had normal or corrected-to-normal visual acuity.

Apparatus and Stimuli. All experiments were carried out on a Pentium IBM compatible computer equipped with an NEC Multisync E700 color monitor and were programmed in Turbo Pascal. Participants were seated approximately 40 cm from the monitor. Responses were made using a Gravis digital joystick that was interfaced to the computer via a standard joystick input port located on the sound card. Reaction times were measured using the routines published by Bovens and Brysbaert (1990).

The stimuli in any given display appeared in two of four locations, marked by light grey boxes just above, below, left, and right of fixation. The boxes were positioned such that the horizontal visual angle between the centers of the left and right boxes was 5.0° and the vertical visual angle between the centers of the top and bottom boxes was 4.3°. Each box subtended a visual angle of 1.6° horizontally and 1.7° vertically. The letter O appeared in the center of one of the boxes and the letter X appeared inside another of the boxes in each stimulus display. Both letters were light grey and subtended 0.9° horizontally and 1.0° vertically.

Procedure and Design. Instructions appeared on the screen at the beginning of the experiment and were subsequently clarified by the experimenter to ensure that they were understood. Participants were told that an X and an O would each appear in two of the four boxes on both of two consecutive displays (prime and probe; see Figure 1). The task was to keep an updated count of the number of times the letter X appeared in either the top or bottom boxes for the prime display, and to indicate the location of the target letter O for the probe display; no manual response was required for the prime display. At the end of each block of trials, the experimenter asked the subject to report his/her tally. Participants recorded their responses to the probe stimulus by moving a joystick in a direction that was spatially compatible with the location of the target (up, down, left, or right). Speed and accuracy of responses were both emphasized. Incorrect responses were indicated to the subject by a beep that sounded from the computer and responses that took longer than 3000 ms were also scored as incorrect.

Participants began each trial by depressing the start key on the joystick. The four location markers subsequently appeared on the screen and remained for the duration of the trial. One second after the onset of the location markers, the prime display appeared and remained on the screen for a duration of 157 ms. Following offset of the prime, there was a brief pause of 500 ms, followed by onset of the probe display. The probe display also remained visible for 157 ms. At this point, participants were to indicate the location of the target letter O with the appropriate joystick response. After each joystick response a brief 50 ms click was produced, which signaled to the participant that their response had been registered. A louder click was emitted if the participant responded incorrectly. After the participant responded to the probe display, the screen was cleared and a prompt appeared instructing the participant to begin a new trial.

There were three conditions tested in this experiment. In the Location-change condition both the O and X of the probe display appeared in locations that were unoccupied in the prime display. In the Location-repeat/Identity-match condition, the O in the probe display appeared in the location occupied by the O in the prime display while the X in the probe display appeared in an unoccupied prime location. In the Location-repeat/Identity-mismatch condition, the O in the probe display appeared in the location occupied by the X in the prime display, while the X in the probe display appeared in an unoccupied prime location. The relative proportions of these three conditions were as follows: .75 Location-repeat/Identity-mismatch condition, .08 Location-repeat/Identity-match condition, and .17 Location-change condition. These relative proportions were achieved by including eighteen Location-repeat/Identity-mismatch trials, two Location-repeat/Identity-match trials, and four Location-change trials in each block of 24 trials. After every two blocks of trials, the experimenter asked the subject to report his/her tally of the number of times the X in the prime display appeared in either the top or bottom boxes. Subject reports were later compared with an objective record in order to compute counting accuracy.

Each participant completed a practice session in which the relative proportions of the three conditions was the same as in the test session, and in which they made a minimum of three correct responses per condition. The test session consisted of 12 blocks of trials with a one-minute break every 2 blocks (i.e., every 48 trials). When participants finished the task they were given a questionnaire designed to assess any explicit knowledge regarding the percentage of Location-repeat/Identity-mismatch trials. In addition to asking about the proportion of trials, the questionnaire also queried participants with regard to the use of a particular strategy during the experimental session. Specifically, we were interested in whether subjects used the prime X strategically to predict the location of the probe target O. To more clearly assess explicit knowledge relating to proportion of Location-repeat/Identity-mismatch trials, participants were shown a drawing that depicted the three experimental conditions (Location-change, Location-repeat/Identity-match and Location-repeat/Identity-mismatch), and they were required to estimate the percentage of Location-repeat/Identity-mismatch trials that occurred.

Results

Our strategy for data analysis across all of the experiments is as follows. First, we report an overall RT analysis collapsing across participants' subjective reports of awareness. If there are sufficient numbers of participants in each of the awareness groups, then we report an analysis examining RT as a function of reported awareness. If there are insufficient numbers of participants to perform a statistical analysis based on group, then we simply report the pattern of RT results for each group, noting any interesting trends in the data. In previous work (Vaquero et al., 2010), we also conducted analyses based on reported strategy use, which often provided us with a clearer picture than analyses based on reported awareness alone. For reasons that are not immediately clear, this was not the case in the current experiments. For this reason, our reported analyses focus on participants' reports of contingency awareness only.

Overall Analysis. RTs for trials in which the probe response was correct were submitted to an outlier analysis to eliminate any unusually fast or slow responses. The outlier elimination procedure determined a cut-off criterion based on sample size for each condition so as to not systematically exclude more trials in cells with fewer RTs (see Van Selst & Jolicoeur, 1994). Approximately 2.5% of the RTs were eliminated using this procedure. Mean RTs for each condition were then computed based on the remaining observations in each cell, and these mean RTs were then analyzed with a one-way repeated measures analysis of variance (ANOVA). For all analyses reported in this paper, degrees of freedom were adjusted using the Huynh-Feldt correction for violations of sphericity where appropriate. All post-hoc comparisons were evaluated using Fisher's LSD procedure. Overall mean RTs for each condition, as well as means broken down by awareness of the high proportion of Location-repeat/Identity-mismatch trials , are presented in Table 1.

The ANOVA revealed a significant main effect of trial type, $F(2, 30) = 4.68$, $p <.05$. Subsequent comparisons revealed that responses for Location-repeat/Identity-mismatch trials (675 ms) were slower than responses for Location-change trials (643 ms), $t(15) = -5.2$, $p <.001$, and responses for Location-repeat/Identity-match trials (661) were likewise slower than responses for Location-change trials, $t(12) = -1.8$, $p <.05$[1].

The mean error rates for each condition are displayed in Table 2. A one-way ANOVA comparing error rates across conditions revealed no significant effect of trial type. The pattern of error rates was consistent with the RT data, thus lending no support to a speed-accuracy trade-off interpretation of the RT results.

Analysis Based on Reported Contingency Awareness. The mean estimate of the percentage of Location-repeat/Identity-mismatch trials given by all participants was 36.5%. In fact, only 2 out of 16 participants gave an estimate greater than 50%. Following Vaquero et al. (2010), we classified our participants as "aware" if their estimate was greater than 50%, and "unaware" if their estimate was less than or equal to 50%. The mean percentage estimate of the Location-repeat/Identity-mismatch trials for the aware and unaware groups was 83% and 30%, respectively. By this criterion of awareness, this result strongly suggests that keeping a running tally of the number of times the prime X appeared in the top or bottom location was insufficient to produce awareness of the strong contingency. Indeed, the counting task appeared not to raise the level of awareness of the contingency at all relative to that reported in Experiment 1 of Vaquero et al. (2010).

Separating the RT data based on reported awareness revealed the same pattern of data for both groups of subjects. Responses were slower to both Location-repeat/Identity-mismatch and Location-repeat/Identity-match trials compared to Location-change trials. Both of the two participants who were reportedly aware of the contingency nonetheless responded in the same way as those participants who were unaware.

Discussion

Focusing first on participants' subjective awareness, the results of Experiment 1 indicate that an explicit requirement to selectively process the prime X resulted in no appreciable gain in awareness of the strong contingency between prime X and probe O relative to the passive prime procedure of Vaquero et al. (2010). Recall that our intuition at the outset of this study was that attention to the prime X ought to raise awareness of the contingency to near ceiling level. The results of this experiment constitute a first piece of evidence that our intuition was naïve.

Turning to the behavioural data, participants were slower to localize the probe O when it appeared in the same location as the prime X despite the fact that these trials occurred 75% of the time. That we were able to obtain such an IOR effect in the presence of a very strong contingency favoring location-repeat trials suggests that participants were unable to capitalize on this contingency and override the slowing produced by IOR.

Experiments 2a & 2b

Although we were puzzled that verbal reports of the contingency were insensitive to the counting manipulation in Experiment 1, we noted that RTs were about 200ms slower than those reported by Vaquero et al. (2010). This result suggests that our counting manipulation may have introduced a significant cognitive load to the task. Such a cognitive load could have interfered with processes that bind the relations between successive events. With this idea in mind, we aimed to examine the role of attention in learning of the prime-X/probe-O contingency using an attentional requirement that did not introduce a cumulative cognitive load for participants.

Experiment 2a followed the same basic procedure as Experiment 1, but rather than counting the occasions in which the prime X appeared in the top or bottom locations, participants were asked to name aloud the color in which the prime X appeared. The prime X and prime O were each displayed in one of four colors (blue, green, red, or purple) with the stipulation that they not be the same color on any given trial. To further ease the cumulative burden of attending to the prime X on each trial and therefore to render unlikely a cognitive load interpretation for the results, we lengthened the inter-stimulus-interval (ISI) from 500 ms to 1100 ms, which gave participants plenty of time to name the color of the prime X and then prepare to locate the probe O. We also ran a control experiment (Experiment 2b) in which participants saw displays identical to those in Experiment 2a but were required to observe the prime stimulus passively rather than identify the color of the prime X. Any difference in performance between these two experiments can therefore be safely attributed to the requirement to attend to the color of the prime X. The key question was whether this form of attention to the prime X would lead participants to become aware of the contingency between the prime X and probe O.

Experiment 2a

Method

Participants. Thirty-five undergraduate students from an introductory psychology course at McMaster University participated in exchange for course credit. The mean age of participants was 18.6 years. All participants had normal or corrected-to-normal visual acuity.

Procedure and Design. The procedure and design for Experiment 2a was identical to that for Experiment 1 with the exception that participants were instructed to name aloud the color in which the prime X appeared rather than count the occasions in which the prime X appeared in the top or bottom location. Both the O and X in the prime appeared in one of four colors (red, green, blue, purple) with the constraint that they could not both appear in the same color on any given trial. It was emphasized that participants should report aloud the color of the prime X as soon as possible after its onset, such that their verbal response would be complete prior to the onset of the probe stimulus. Color naming responses were recorded by the experimenter. In addition, the ISI between prime and probe stimuli was lengthened from 500 ms in Experiment 1 to 1100 ms in Experiment 2a, to allow sufficient time for the naming task prior to onset of the probe.

Results

Overall Analysis. Correct RTs were submitted to the same outlier exclusion procedure used in Experiment 1. This procedure resulted in the elimination of approximately 2.5% of all trials. Trials were also excluded from RT analyses if participants made an incorrect color naming response to the prime X (<2 % of all trials). Mean RTs were computed from the remaining observations and were submitted to a one-way repeated measures ANOVA to assess the effects of trial type. The analysis revealed a significant main effect of trial type, $F(2, 68) = 6.1, p < .05$. Subsequent tests revealed that responses to Location-repeat/Identity-mismatch trials (456 ms) were faster than responses to Location-change trials (469 ms), $t(34) = 2.0, p < .05$, but responses to Location-repeat/Identity-match trials (478 ms) were slower than responses to Location-change trials, $t(34) = -2.6, p < .05$.

The mean error rates for the Location-change, Location-repeat/Identity-mismatch, and Location-repeat/Identity-match trial types were 2.3%, 3.0%, and 1.9% respectively. A repeated measures ANOVA revealed no differences in the error rates among the trial types.

Analysis Based On Reported Contingency Awareness. 25 of 35 (71%) participants gave an estimate of the percentage of Location-repeat/Identity-mismatch trials that was greater than 50%. The mean percentage estimate of these trials for the aware and unaware groups was 75% and 28%, respectively. Although more participants were aware of the contingency in this experiment than in Experiment 1, $X^2(1) = 15.3, p < .001$, it remains somewhat surprising that 10 participants who selectively attended and responded to the prime X failed to recognize a very strong contingency between that prime X and a probe O that appeared in the same location just 1100 ms later. Note that these Location-repeat/Identity-mismatch trials occurred on approximately 180 of the total 240 trials across an experimental session of about 30 minutes in duration. Six times a minute participants were faced with a Location-repeat/Identity-mismatch trial, and some participants appeared not to notice them despite attending and responding to the prime X.

Mean RTs were analyzed as a function of subjective reports of awareness of the contingency, with those giving estimates of the percentage of Location-repeat/Identity-mismatch trials greater than 50 being classified as aware, and those giving estimates of 50 or lower being classified as unaware. A mixed factor analysis of variance was conducted, which treated awareness (aware/unaware) as a between-subjects factor and trial type (Location-change, Location-repeat/Identity-mismatch)[2] as a within-subject factor. Mean RTs for each condition are displayed in Table 1.

The ANOVA revealed a significant interaction between group and trial type, $F(1, 33) = 7.88$, $p < .01$. In examining this interaction further, a subsequent comparison revealed that for the aware group, responses to Location-repeat/Identity-mismatch trials were faster (446 ms) than responses to Location-change trials (468 ms), $t(24) = 3.03$, $p < .01$. Furthermore, in the unaware group, responses to Location-repeat/Identity-mismatch trials (483 ms) were slower than responses to Location-change trials (471 ms), $t(9) = 2.0$, $p < .05$ (one-tailed). These results are shown in Figure 2.

The mean error rates for each condition separated by awareness are displayed in Table 2. ANOVAs that corresponded to those conducted on the mean RTs revealed no significant effect. For both aware and unaware groups the pattern of error rates was consistent with the RT data, thus lending no support to a speed-accuracy trade-off interpretation of the RT results.

Experiment 2b

Method

Participants. Eighteen undergraduate students from an introductory psychology course at McMaster University participated in exchange for course credit. The mean age of participants was 18.4 years. All participants had normal or corrected-to-normal visual acuity.

Procedure and Design. The procedure and design for Experiment 2b were identical to those of Experiment 2a with the exception that participants were instructed to passively watch the prime stimulus and respond only to the probe. The ISI between prime and probe stimuli was 1100 ms as in Experiment 2a.

Results

Overall Analysis. The mean RTs for each condition are shown in Table 1. RTs were submitted to the same outlier procedure used in Experiment 1, which eliminated approximately 2.4 % of all trials. Mean RTs computed from the remaining observations were submitted to a one-way repeated measures ANOVA with Trial Type as our variable of interest. This analysis revealed a significant main effect of trial type, $F(2, 34) = 8.92$, $p <.01$. Subsequent tests indicated that responses to Location-repeat/Identity-mismatch trials (405 ms) were slower than responses to Location-change trials (394 ms), $t(17) = -4.6$, $p <.001$, and responses to Location-repeat/Identity-match trials (402 ms) were also slower than those to Location-change trials, $t(17) = -2.8$, $p <.05$.

Analysis Based on Reported Contingency Awareness. 4 of 18 (22%) participants gave estimates of the percentage of Location-repeat/Identity-mismatch trials that were greater than 50%. The mean percentage estimate of these trials for the aware and unaware groups was 78% and 37%, respectively. This proportion of aware participants is substantially smaller than the corresponding proportion in Experiment 2a, $X^2(1) = 11.6$, $p < .001$. Indeed, contingency awareness fell back to the level observed in Experiment 1.

Although we did not analyze the RTs as a function of reported contingency awareness, roughly the same pattern of RTs was observed across trial type for the aware and unaware groups.

The mean error rates for each condition are shown in Table 2. A one-way ANOVA on the mean error rates revealed no significant effect of Trial Type, however the pattern of error rates was generally consistent with the RT data.

Discussion

In Experiment 2a, participants were instructed to attend selectively to the color of the X presented in the prime, while responding to the spatial location of the target O in the probe. Our prediction was that attending to the prime X in the context of a task with a small cognitive load would lead to an overwhelming majority of participants becoming aware of the contingency. In fact, whereas 71% of participants gave high estimates of the proportion of Location-repeat/Identity-mismatch in Experiment 2a, just 22% of participants did so in Experiment 2b. These results clearly suggest that the attention manipulation employed in Experiment 2a had a sizable impact on explicit knowledge of the contingency.

In addition, the requirement to attend selectively to the prime X led to a qualitative difference pattern in Experiment 2a. For those subjects who were classified as explicitly aware of the contingency (estimates of Location-repeat/Identity-mismatch trials > 50%), responses were *faster* for Location-repeat/Identity-mismatch trials relative to Location-change trials. For those subjects who were classified as unaware of the contingency (≤ 50%), responses were *slower* for Location-repeat/Identity-mismatch trials relative to Location-change trials. Thus it seems as though participants classified as aware of the contingency may have used the prime-probe relationship in a strategic manner to predict the location of the probe target O. Such a conscious strategy might override the IOR effect and lead to faster responses on Location-repeat/Identity-mismatch trials relative to Location-change trials. This *qualitative difference* in behavior as a function of explicit awareness of the contingency mirrors that obtained by Vaquero et al. (2010).

Despite the effectiveness of the attention manipulation in Experiment 2a, it remains somewhat surprising that nearly 30% of our participants remained “blind” to the strong experimental contingency. If low estimates of the proportion of Location-repeat/Identity-mismatch trials reflect a form of inattentional blindness (Mack & Rock, 1998), then it follows that our attention manipulation ought not to have left 30% of the participants attentionally blind.

One possible explanation for this result is that the information participants were required to select (color of the prime X) is orthogonal to the information that defines the dimension on which the contingency is based. While participants may have in some sense “attended” to the prime X, the information that was selected may not have been relevant to the discovery of the contingency. Other researchers have indeed suggested that attention and selection can be dissociated from one another (Remington & Folk, 2001), and that the information that is ultimately selected from an attended item depends largely on the top-down constraints imposed by the task requirements. Therefore, attention to the prime X might be more effective in bringing levels of contingency awareness to ceiling if the task forced participants to select information that corresponds to the dimension on which the contingency is defined. By this view, given that the contingency in our experiments is defined by location, requiring participants to select the location of the prime X should certainly lead to ceiling levels of contingency awareness. We tested this idea in Experiments 3a & 3b by requiring subjects either to report vocally the location of the prime X (Experiment 3a), or to localize the prime X using a joystick response (Experiment 3b) prior to making a joystick localization response for the probe O.

Experiments 3a & 3b

In these experiments the task requirements drew attention to the spatial location of the prime X. Given that the critical contingency was defined by a high likelihood of the prime X appearing in the same location as the probe O, this method seemed ideal to assess the impact of attention on awareness of the contingency. Participants in Experiment 3a were to name aloud the location of the X in the prime while responding to the location of the probe O with a joystick. Participants in Experiment 3b were required to make a joystick response to the location of the prime X followed by a second joystick response to the location of the probe O. Given that participants' task was to *localize* both the prime X and the probe O in these experiments, we hypothesized that awareness of the prime-probe contingency ought finally to reach the ceiling levels that we had originally predicted. Specifically, we anticipated that all of our participants in both experiments would report being aware of the contingency, and that this awareness would lead them to respond faster to the frequent Location-repeat/Identity-mismatch trials than to Location change trials.

Experiment 3a

Method

Participants. Eighteen undergraduate students from an introductory psychology course at McMaster University participated in exchange for course credit. The mean age of participants was 19 years. All participants had normal or corrected-to-normal visual acuity.

Procedure and Design. The procedure and design for Experiment 3a were identical to those in Experiment 2a with the exception that participants were instructed to name aloud the location in which the prime X appeared (top, bottom, left or right) rather than naming aloud the color of the prime X. All letter stimuli in this experiment were presented in white. It was emphasized that participants should report aloud the location of the prime X as soon as possible, which ensured that their verbal response would be complete prior to the onset of the probe. Naming responses were recorded by the experimenter. The ISI between prime and probe stimuli was 1100ms as in Experiment 2a.

Results

Overall Analysis. Correct RTs were submitted to the same outlier exclusion procedure used in Experiment 1. This outlier analysis resulted in the elimination of approximately 2.9% of all trials. Trials were also excluded from RT analyses if participants made an incorrect location naming response to the prime X (<2 % of all trials). Mean RTs were computed from the remaining observations and were submitted to a one-way repeated measures ANOVA to assess the effects of Trial Type. There was a significant main effect of Trial Type, $F(2, 34) = 8.28$, $p <.01$, and subsequent comparisons indicated that responses to Location-repeat/Identity-mismatch trials (489 ms) were slower than responses to Location-change trials

(463 ms), *t*(17) = -5.40, $p < .001$. Additionally, responses to Location-repeat/Identity-match trials (483 ms) were slower than responses to Location-change trials, *t*(17) = -2.72, $p < .05$.

The mean error rates for the Location-change, Location-repeat/Identity-mismatch, and Location-repeat/Identity-match trial types were 3.0%, 3.0%, and 2.7% respectively. A repeated measures ANOVA revealed no differences in the error rates among the trial types.

Analysis Based On Reported Contingency Awareness. 11 of 18 (61%) participants gave an estimate of the percentage of Location-repeat/Identity-mismatch trials that was greater than 50%. The mean percentage estimate of these trials for the aware and unaware groups was 74% and 39%, respectively. Although much higher than the 13% of participants who gave high estimates in Experiment 1, $X^2(1) = 7.7$, $p < .01$, it is clear that having participants attend and report the location of the prime X did not raise the number of aware participants beyond the 71% level observed in Experiment 2a. Again, it struck us as particularly surprising that almost 40% of participants who selectively attended and responded to the prime X by saying aloud, for example, “top”, and then on 75% of trials pushed a joystick toward the probe O in the top location, failed to identify a very strong contingency between a prime X and probe O separated by just 1100 ms.

For the RT analysis, participants were classified into two groups (aware/unaware). Participants giving estimates of the proportion of Location-repeat/Identity-mismatch trials greater than 50 % were classified as aware while the remaining participants were classified as unaware. Mean RTs were submitted to mixed factor analyses of variance that treated Group (aware/unaware) as a between-participants factor and Trial Type (Location-change, Location-repeat/Identity-mismatch)[2] as a within-subject factor. Mean RTs for each condition are displayed in Table 1.

The ANOVA revealed a significant main effect of Trial Type, $F(1, 16) = 8.32$, $p < .01$, but no other effects that reached significance. Responses to Location-repeat/Identity-mismatch trials (489 ms) were slower than responses to Location-change trials (463 ms). These data are presented in Figure 3.

The mean error rates for each condition separated by awareness are displayed in Table 2. ANOVAs that corresponded to those conducted on the mean RTs revealed no significant effects.

Experiment 3b

Method

Participants. Twenty-six undergraduate students from an introductory psychology course at McMaster University participated in exchange for course credit. The mean age of participants was 20.4 years. All participants had normal or corrected-to-normal visual acuity.

Procedure and Design. The procedure and design for Experiment 3b were identical to those of Experiment 3a with the exception that participants were now instructed to respond to the location of the prime X with a speeded joystick movement prior to responding to the location of the probe O in precisely the same way. It was emphasized that *both* joystick responses should be executed as quickly as possible while maintaining a high level of accuracy. The ISI between prime and probe stimuli was 1100 ms as in Experiment 3a.

Results

Overall Analysis. Correct RTs were submitted to the same outlier exclusion procedure used in Experiment 1, which resulted in the elimination of approximately 2.9% of all trials. For a trial to be considered correct, correct localization responses to both the prime and probe were required. Mean RTs were computed from the remaining observations and were submitted to a one-way repeated measures ANOVA to assess the effects of Trial Type. The effect of trial type did not reach significance in this RT analysis. The mean RTs for each trial type are presented in Table 1.

The mean error rates for the Location-change, Location-repeat/Identity-mismatch, and Location-repeat/Identity-match trial types were 2.1%, 3.6%, and 3.2% respectively. A repeated measures ANOVA revealed no differences in the error rates among the trial types.

Analysis Based On Reported Contingency Awareness. 18 of 26 (69%) participants gave an estimate of the percentage of Location-repeat/Identity-mismatch trials that was greater than 50%. The mean percentage estimate of these trials for the aware and unaware groups was 70% and 39%, respectively. Similar to Experiment 3a, the proportion of participants classified as aware exceeded that observed in Experiment 1, $X^2(1) = 12.8$, $p < .001$, but was numerically *less* than the corresponding proportion obtained in Experiment 2a. The fact that more than 30% of our participants remained blind to the strong contingency after executing the very same response twice on 3 out of every 4 trials seemed especially noteworthy and counterintuitive.

RT analysis proceeded in much the same fashion as in Experiment 3a. Participants were assigned to groups (aware/unaware) based on their responses to the post-experiment questionnaire. Mean RTs for each condition are displayed in Table 1. A mixed factorial ANOVA was conducted with Trial Type (Location-change, Location-change/Identity-mismatch)[2] as a within-subjects factor, and Group (Aware/Unaware) as a between-subjects factor. There were no reliable effects of either variable nor was there a reliable interaction. These data are depicted in Figure 4.

The mean error rates for each condition separated by awareness are displayed in Table 2. ANOVAs that corresponded to those conducted on the mean RTs revealed no significant effects.

Discussion

In Experiments 3a & 3b , we tested the hypothesis that requiring participants to select information from the prime that was directly related to the dimension on which the contingency was defined would lead all of our participants to be aware of the contingency. With this procedure, on 75% of the trials, the location that subjects named aloud (Experiment 3a) or responded to (Experiment 3b) in the prime was the exact same location that they responded to with the joystick in the probe. Given this stark overlap between the responses for the prime and probe, not only should all our participants be aware of the contingency, but we also assumed that consequent use of this contingency should result in uniformly fast responses for Location-repeat/Identity-mismatch trials for all participants.

It would have been difficult to be more incorrect in our predictions. Results from Experiment 3a revealed that close to 40% of participants appeared unaware of the high contingency between prime X and probe O. This result is in stark contrast to the hypothesis that selecting the relevant contingency-related information from the prime would lead to ceiling levels of awareness. In fact, the proportion of participants classified as aware in Experiment 3a was numerically *less* than the corresponding proportion obtained in Experiment 2a.

In addition, the behavioral performance was no different for those who were aware and those who were unaware. Responses were slower for the Location-repeat/Identity-mismatch condition than for the Location-change condition for both groups. When asked about strategy use, the data were no different. Although 13 of 18 participants reported using a strategy to respond to the probe O, the behavioral performance was no different for those who were strategic than for those who were not strategic.

In Experiment 3b, we found yet again that a large percentage of our participants (>30%) were unable to accurately judge the proportion of Location-repeat/Identity-mismatch trials. The fact that executing the very same response to both the prime and probe on 75% of trials led to levels of awareness comparable to that observed when subjects named the color of the prime X (Experiment 2a) suggests an upper limit on the level of awareness that can be obtained by selecting the relevant information from the prime display.

Similar to Experiment 3a, we did not find the qualitative difference pattern of behavior that was obtained in Experiment 2a. The behavioral results from Experiment 3b indicated that RTs to Location-repeat/Identity-mismatch trials were no different than RTs to Location-change trials, for both aware and unaware subjects. The fact that a significant IOR effect was observed in Experiment 3a but not in Experiment 3b suggests that perhaps participants in Experiment 3b were able to capitalize on the very same joystick response being required for prime and probe on 75% of the trials. Yet, the fact that this preponderance of response repetitions in the experiment resulted in no better than a null priming effect suggests strongly that there is some other process that slows responses in Location-repeat/Identity-mismatch trials despite their high frequency. We return to this issue in the General Discussion.

We began this study with the aim of assessing whether the profound levels of unawareness of a contingency reported by Vaquero et al. (2010) were related to mere inattention to the prime X in favor of attention to the prime O. Our assumption was that there ought to be some straightforward manipulation of attention that would yield near ceiling levels of awareness of a strong contingency between prime X and probe O. Although requiring participants to attend to the prime X by naming its color, naming its location, or overtly responding to its location certainly raised awareness of the contingency well off the floor, none of these attentional manipulations threatened ceiling levels of awareness. The results from Experiments 3a and 3b definitively rule out the hypothesis that for participants to become aware of the location-based contingency, they simply need to select the relevant contingency defining information from the prime display. The stubborn presence of an appreciable number of participants who report low percentages of trials in which the prime X and probe O appear in the same location seems particularly odd when participants are required to locate the prime X and also to locate the probe O.

Indeed, the results of Experiments 1-3 were sufficiently surprising that they led us to re-evaluate what we considered to be “ceiling” levels of performance in subjective report of the contingency. In Experiment 2 of Vaquero et al. (2010), a probe O appeared in the same location as a prime O on 75% of trials, and 11 of 12 participants appeared to be aware of this contingency (i.e., they gave estimates of the percentage of Location-repeat/Identity-match trials greater than 50%). As a result, we had assumed that it was indeed possible to achieve a result in which 85-90% of participants report awareness of a strong contingency in a study of this nature. At this point, it seemed prudent to replicate this experiment, to ensure that the results of the present study do not merely reflect an inability to make accurate percentage estimates on the part of a stable 30% or so of the population from which we sampled.

Experiment 4

This experiment was a direct replication of Experiment 2 of Vaquero et al. (2010). The procedure was similar to that used in previous experiments reported in this article, with two exceptions. First, participants were required to respond only to the probe O, and were not given an attentional task with respect to the prime display. Second, the probe O appeared in the same location as the prime O rather than the prime X on 75% of the trials. In Experiment 2 of Vaquero et al. (2010), 11 of 12 participants gave an estimate of the percentage of Location-repeat/Identity-match trials greater then 50%. Here we ask simply whether this result can be replicated in light of several failed attempts to reach comparably high levels of awareness of contingencies involving Location-repeat/Identity-mismatch trials and a series of attention manipulations in Experiments 1-3. This experiment was intended to serve as a demonstration that the surprising lack of awareness observed in Experiments 1-3 is not a reflection of a general lack of ability to estimate contingencies, but rather reflects the importance of feature mismatches in obscuring awareness of such contingencies.

Method

Participants. Twelve undergraduate students from an introductory psychology course at McMaster University participated in exchange for course credit. The mean age of participants was 19.1 years. All participants had normal or corrected-to-normal visual acuity.

Procedure and Design. The procedure in this experiment was similar to that used in Experiment 1 with the exception that 75% of the trials were of the Location-repeat/Identity-match type, in which the probe O appeared in the same location as the prime O, 17% of the trials were of the Location-change type, and 8% of the trials were of the Location-repeat/Identity-mismatch type. In addition, participants were given no attention task with respect to the prime display, and instead were instructed simply to observe the prime display and respond only to the location of the O in the probe display.

Results

Overall Analysis. Correct RTs were submitted to the same outlier elimination procedure used in previous experiments, which resulted in the elimination of approximately 2.5% of the RTs from further analysis. Mean RTs were computed based on the remaining observations, and were submitted to a repeated measures ANOVA that treated trial type (Location-change, Location-repeat/Identity-mismatch, Location-repeat/Identity-match) as the lone within-subject factor. Mean RTs for each condition are displayed in Table 1. This analysis revealed a significant main effect of Trial Type, $F(2, 22) = 26.5$, $p <.001$. Responses to Location-repeat/Identity-match trials (405 ms) were faster than responses to Location-change trials (439 ms), $t(11) = 4.7$, $p <.001$, and responses to Location-repeat/Identity-mismatch trials (462 ms) were slower than responses to Location-change trials, $t(11) = -4.1$, $p <.01$.

The mean error rates for each condition are displayed in Table 2. A one-way repeated measures ANOVA on these error rates revealed no significant effect of Trial Type. Inspection of the error rates in Table 1 reveals a pattern that is consistent with the RT data, and thus there is no support for a speed-accuracy tradeoff interpretation of the RT results.

Analyses Based on Reported Contingency Awareness. 10 of 12 (83%) participants gave an estimate of the percentage of Location-repeat/Identity-mismatch trials that was greater than 50%. The mean percentage estimate for such trials was 72% and 38% for the aware and unaware groups, respectively. This result constitutes a close replication of Experiment 2 in Vaquero et al. (in press), in which 11 of 12 participants gave high estimates of the proportion of Location-repeat/Identity-mismatch trials. For the 2 participants who gave low estimates (<=50%) their RT data followed the same pattern as those giving higher estimates (>50%). Both unaware participants responded faster to Location-repeat/Identity-match trials than to Location-change trials, and responded slower to Location-change/Identity-mismatch trials than to Location-change trials.

Comparison with Experiments 1-3. To compare the level of awareness obtained in Experiment 4 with that of Experiments 1-3, we performed four separate chi-square tests. A summary of these comparisons can be seen in Table 3. To increase the power of our comparisons, we add the data from Experiment 2 of Vaquero et al. (2010) with the data from Experiment 4 of the current work. Given that Experiment 4 was a direct replication of Experiment 2 from Vaquero et al., it makes sense to do so. With these new data added, 21 out of 24 participants were classified as aware of the contingency. Comparing the level of awareness obtained in Experiment 4 (21/24) with that of Experiment 1 (2/16), we found that a larger number of participants in Experiment 4 were classified as aware of the contingency, $X^2(1) = 22.1$, $p < .001$. Comparing Experiment 4 with Experiment 2a (25/35) revealed no difference in levels of awareness, $X^2(1) = 2.1$, $p = .14$, despite a trend in the expected direction. In comparing Experiment 4 with Experiment 3a (11/18) however, there were more participants classified as aware of the contingency in Experiment 4, $X^2(1) = 3.9$, $p < .05$. The corresponding comparison between Experiment 4 and Experiment 3b did not reach significance, $X^2(1) = 2.4$, $p = .12$, despite once again a trend in the expected direction.

Discussion

The purpose of Experiment 4 was to address the concern that the observed "blindness" to otherwise obvious contingencies in Experiments 1-3 was not a manifestation of a general inability to accurately estimate percentages of salient trial types. The results obtained here replicate those found in Vaquero et al. (2010), and add further substance to the idea that it is *not* the case that people are just generally poor at estimating contingencies. Participants were quite able to accurately estimate the proportion of Location-repeat/Identity-match trials in this experiment. Furthermore, although selective attention may enhance subjects' ability to estimate contingencies in some of our experiments (Experiments 2a, 3a, & 3b), the results of the present experiment suggest that object integration processes also play an important role. In fact, the current experiment did not contain an explicit requirement to attend to the prime and yet we witnessed levels of awareness that were greater than those observed when attention to the prime was required (Experiments 2a, 3a, b). Contingency estimates appear to be more accurate when a current target event matches in both its spatial location and its identity with the prime event with which it is associated strongly. We conclude that attention may well have impacted participants' awareness of contingencies in the study of Vaquero et al. (2010). However, we conclude also that the extent to which one simply "pays attention" to the relevant events cannot fully explain the surprisingly low levels of contingency awareness in Experiment 1 of Vaquero et al. and in the experiments reported here. Rather, the contrast between high levels of contingency awareness involving location-identity matches (Experiment 4) and lower levels of contingency awareness involving location-identity mismatches (Experiments 1, 2a, 2b, 3a, 3b) suggest that bottom-up event integration processes may play an important role in awareness of event contingencies.

General Discussion

The research described in this article examined the role of attention in the explicit learning and report of strong contingencies in a trial to trial performance context. The specific rationale for the research stems from a surprising result reported recently by Vaquero et al. (2010), in which participants demonstrated a profound inability to report accurately the presence of a strong contingency in a spatial priming task. This finding could conceivably be related to a well-known phenomenon in the attention literature known as inattentional blindness (Mack & Rock, 1998). Although Vaquero et al. provided some initial, indirect evidence that attention affects contingency awareness, our goal was to test this idea directly by manipulating the information participants were required to select and process.

To address this issue, Experiments 1, 2a, 3a, and 3b used a variety of methods to direct participants' attention to the predictive prime event. Our initial hypothesis regarding this set of experiments was straightforward: Attention to the predictive prime event ought to allow all of our participants to be able to report the contingency accurately. The critical predictive prime event in Experiments 1-3 was an X located in one of four spatial locations. Attention to the prime X was manipulated in Experiment 1 by asking participants to count the number of times it occurred in the top or bottom locations, in Experiment 2a by asking participants to identify the color in which the prime X was presented, in Experiment 3a by asking participants to identify the location in which the prime X was presented, and in Experiment 3b by asking participants to *respond* to the location of the prime X with a spatially compatible joystick movement.

Attention and Explicit Awareness of Contingencies

Across the experiments, there was certainly evidence that attention to the prime X had an impact on participants' awareness of the trial to trial contingency, in at least some contexts. The clearest evidence for the role of attention is the contrast between the results of Experiments 2a and 2b. The only difference between these two experiments was that participants in Experiment 2a were required to identify the colour of the prime X, whereas participants in Experiment 2b had no such requirement. Whereas 25 of 35 (71%) participants in Experiment 2a gave estimates of the percentage of Location-repeat/Identity-mismatch trials of greater than 50, only 4 of 18 (22%) participants gave such estimates in Experiment 2b. This large difference in the percentage of participants who displayed an awareness of the contingency shows clearly that attention to the prime X, in the form of a requirement to identify its colour, can impact whether participants become explicitly aware of a contingency between the prime X and a following probe O that often appears in the same location.

This result is consistent with one of the key results reported by Vaquero et al. (2010; Experiments 1 and 3). In Experiment 1 of their study, both an O and an X appeared as primes, and just 14% of the participants appeared to be aware of the strong contingency that had been introduced between prime X and probe O. In Experiment 3, removal of the prime O resulted in approximately half of the participants being aware of this contingency. The authors interpreted this result as support for the idea that inattention to the prime X contributed to low levels of awareness in Experiment 1. In particular, the requirement to respond to the probe O may have introduced a preparatory set that resulted in a shift of attention toward the prime O and away from the prime X in Experiment 1, and consequently a low level of contingency awareness. In contrast, the absence of a prime O in Experiment 3 would eliminate this shift of attention away from the prime X, and consequently led to a higher level of contingency awareness.

To this point, the results of the current paper align very closely with those reported by Vaquero et al. (2010). Clearly, attention can play a role in determining awareness of contingencies in our behavioral task. However, the unique contribution of the results reported here is that they illustrate that object integration processes themselves play a role in controlling awareness of contingencies.

Non-attentional Contributions to Explicit Awareness of Contingencies

Although attention to the critical predictive event did contribute to explicit awareness of the contingency in some contexts, there was ample evidence across the experiments that attention to the prime X, in and of itself, was often insufficient to produce high levels of awareness of the strong contingency with the following probe O. First, the counting manipulation in Experiment 1 resulted in just 2 of 16 participants being able to verbalize the contingency, a proportion no higher than that in Experiment 1 of Vaquero et al. (2010). Second, although selective attention to the colour of the prime X in Experiment 2a was effective in increasing the proportion of participants who became aware of the contingency, almost 30% of participants remained unaware. It could reasonably be argued that this high level of unawareness in Experiment 2a owes to participants paying attention to the colour of the prime X, whereas the prime X matched the probe O on 75% of trials not in colour but in location. If attention to the dimension on which the contingency is based were the key ingredient for participants to reliably detect the contingency, then requiring participants to attend and report the location of the prime X ought to have introduced optimal conditions for participants to learn the contingency explicitly in Experiment 3a and 3b. Yet, 39% of participants remained unaware of the contingency in Experiment 3a when participants named aloud the location of the prime X, and 31% of participants remained unaware of the contingency in Experiment 3b when participants made a joystick response to the prime X. In other words, requiring participants to pay attention to the location of the prime X did nothing to raise levels of awareness of the contingency beyond that observed when participants attended to the colour of the prime X in Experiment 2a. This insensitivity of contingency awareness to attention paid to the dimension on which the contingency was based strongly suggests that something other than inattention limits contingency awareness in our study. Third, although there was no specific requirement to attend to the primes in Experiment 4, a greater proportion of participants than in Experiment 3a noted the strong contingency between prime and probe, in this case characterized by a match in both identity and location. Together, these three results strongly suggest that something other than attending and selecting even the most critical information related to the contingency constrains whether participants become aware of the prime-probe contingency.

What are some of the non-attentional factors that might affect the explicit learning of trial to trial contingencies? The data from the present experiments suggest that event integration processes may play a large role. In particular, when the contingency between the prime and probe events involved an identity match (as in Experiment 2 of Vaquero et al., 2010, and Experiment 4 here), a large proportion of participants were able to verbalize the relation (21 of 24). This was not the case when the contingency involved an identity mismatch across prime and probe - participants in this condition were quite poor at verbalizing the contingency. Thus it seems likely that some form of bottom-up feature integration process contributes significantly to the formation of explicit knowledge of contingencies.

To this end, we suggest that the same object-updating processes that influence behavioral performance in tasks such as ours are also crucial in generating awareness of spatial contingencies. Recall that in the framework proposed by Kahneman, Treisman, and Gibbs (1992), the onset of a visual stimulus triggers the creation of an object file – a temporary memory representation containing bound featural information indexed by spatial location. When the spatio-temporal properties of consecutive stimuli match, the visual system is thought to update the contents of an object file, thereby integrating the two events together. However, the speed of this updating process is dependent on the degree of match between the two events - if there is a good overlap in terms of perceptual features, rapid updating occurs. If there is a poor match, object updating is laborious, requiring more time for completion. It may be the case that the good match with respect to perceptual features in the Location-repeat/Identity-match trials allows the visual system to fluently integrate the prime and probe events together. When a poor match in terms of perceptual features is found (as in the Location-repeat/Identity-mismatch trials), the object-file representation created in the prime display cannot be fluently updated with respect to the current display, and so no efficient integration between prime and probe events occurs. This fluent integration due to the rapid updating of an object-file representation could be of critical importance in creating explicit knowledge of contingencies. Indeed, our data are quite consistent with this account.

Alternatively (although not necessarily at odds with the above account), it is possible to interpret this result within a recently forwarded framework that explains how explicit knowledge arises in an incidental learning situation (Frensch, Haider, Runger, Neugebauer, Voigt, & Werg, 2002; Haider, Frensch, 2005). According to Frensch et al. (2002), people discover environmental regularities through an explicit, controlled hypothesis testing process that is triggered by the onset of some relevant source of novelty. Frensch et al. refer to this account as the *Unexpected Event Hypothesis*. According to their model, explicit knowledge of an environmental regularity is always preceded by some unconscious form of learning, which can lead to surprising changes in performance. These surprising changes in performance constitute unexpected events, which lead people to engage in a search process designed to discover their cause. In Experiment 4, it is possible that fluent integration of prime and probe events in the Location-repeat/Identity-match trials served as an unexpected event. If this was the case, our participants might have engaged in a search intended to explain the surprising ease with which they performed the task, and in the process discovered the regularity. In contrast, when such fluent integration of prime and probe was prevented, as in the Location-repeat/Identity-mismatch trials (Experiments 1-3), there would have been no surprising unexpected fluency to trigger a controlled search for the contingency. Although our data do not directly test this hypothesis, our results seem consistent with this account.

Behavioral Effects and Subjective Reports of Awareness and Strategy Use

Our assumption at the outset of this study was that awareness of the strong contingency ought to lead participants to generate an expectancy as to where the probe target would appear based on the location of the prime X. Since participants were instructed to execute a speeded response to the location of the probe target, it makes good sense that participants who were aware of predictive information provided by the prime would use it to aid their responses to the probe. Such a strategy should lead to faster performance on Location-repeat/Identity-mismatch trials relative to Location-change trials. This is precisely the finding reported by Vaquero et al. (2010; Experiment 3 and 4), and we had no a priori reason to expect anything other than the same pattern of results here.

The results of Experiment 2a were consistent with this assumption, as aware participants responded faster to Location-repeat/Identity-mismatch trials than to Location-change trials. However, the results of Experiments 3a and 3b were entirely inconsistent with our assumption. Surprisingly, in Experiment 3a participants were *slower* on Location-repeat/Identity-mismatch trials compared to Location-change trials, while in Experiment 3b, there was no difference in the speed of responses to these two trial types. Clearly, the results of these two experiments suggest that something other than expectation for Location-repeat trials must be constraining performance.

Again, we propose that event binding and integration processes play an important role here. In line with the object file review framework of Kahneman et al. (1992), Hommel and colleagues (Hommel, 1998; Stoet & Hommel, 1999) have suggested that performance in tasks such as ours involves an integration of current perceptual processing with stimulus-response episodes involving recent prior stimuli. Hommel proposes that response features are bound together with perceptual information to create temporary episodic 'event files' that can match or mismatch with subsequent processing episodes. A key property of this framework is the idea that performance is relatively efficient both when the current stimulus and response requirements match perfectly with the immediately preceding stimulus-response episode, and when they mismatch entirely. In contrast, slow performance results from partial matches: that is, when the current stimulus-response episode matches with the preceding stimulus-response episode on one dimension but mismatches on another dimension. Presumably, the feature match on one dimension cues the retrieval of the event file for the preceding trial. However, the feature mismatch on another dimension requires some additional time to sort out, through a form of re-binding of the current feature to the retrieved event file.

Consider now the sequence of events in Experiment 2a. The participant was required to locate the X in the prime and name its color. On the critical Location-repeat/Identity-mismatch trials, the participant was then required to respond to the location of the probe O that occurred in the same location as the prime X. However, the response code generated toward the prime X (its color) did not bear any resemblance to the response code that was subsequently generated in response to the probe O (its location). The key point to note here is that the two task-relevant letters across the prime and probe displays were bound to unique response codes, whereas partial match slowing would be expected to occur if, for example, two task relevant letters were bound to the same response code. As such, the switch from attending/responding to colour in the prime and then to location in the probe may well have reduced the potential for partial match re-binding costs in performance.

In contrast, consider the sequence of events in Experiment 3a. On the critical Location-repeat/Identity-mismatch trials participants were required to respond (vocally) to the location of the prime X and then respond again to the location of the probe O. In this case, the task required the binding of two similar response codes to different letters. As such, partial match costs associated with re-binding similar response codes to different perceptual features were quite likely to affect performance in Experiment 3a. Together, the greater contribution of partial match re-binding costs in Experiment 3a than in Experiment 2a would then explain why different patterns of results were observed across these experiments.

Indeed, the IOR-like result observed in Experiment 3a despite 75% of the trials occurring in the Location-repeated/Identity-mismatch condition is remarkable.

Of course, a similar argument ought to apply to Experiment 3b. On critical trials in Experiment 3b, participants were required to generate two *identical* response codes and bind them with two different perceptual identities. In this experiment, despite Location-repeat/Identity-mismatch trials occurring 75% of the time, response times to such trials were no different than response times to Location-change trials. Again, it follows that partial match costs likely slowed responses in this condition, although in this case partial match slowing may have been offset by a benefit associated with performing the identical action for prime and probe on 75% of the trials.

What is especially intriguing here is the fact that bottom up re-binding processes continue to play a large role in performance in Experiments 3a and 3b, despite the high proportion of Location-repeat/Identity-mismatch trials. One might reasonably predict that conscious knowledge of such a contingency would be used to override the partial match slowing cost, and that performance for aware participants would be faster for Location-repeat/Identity-mismatch trials than Location-change trials in these experiments. Yet, it appears that despite the predictive information offered by the location of the prime X, participants did not use it in a strategic manner that benefited performance. This result highlights the fact that mere awareness of a strong contingency on its own is insufficient to produce the type of qualitative difference result found in Vaquero et al. (2010) and related prior studies (Cheesman & Merikle, 1986; Merikle & Joordens, 1997; Eimer & Schlaghecken, 2002), and merits further thought.

To this end, it may be that partial match re-binding processes implicated in Experiments 3a and 3b affected the *perceived* utility of the contingency. During the questionnaire phase of the task, participants often remarked that they noticed a contingency but were reluctant to use it because it might lead them to make more mistakes. One way in which strategic use of the contingency may lack utility requires an assumption that expectations themselves can activate specific representation of the immediately prior stimulus-response episode. According to this view, whereas participants may have attempted to maintain an expectation that the probe target would appear at the same location as the prime X, the representational basis for the expectation might well have included any information that was bound with that location (i.e., the identity "X"). By this view, the maintenance of an expectation for a probe target O in the same location as a prime X would have the ironic consequence of maintaining precisely the bound stimulus-response episode responsible for partial match costs. The ironic consequence of engaging such strategic expectations might then explain why participants claimed not to find them helpful, and indeed sometimes found them to be counter-productive. A test of this hypothesis might involve specific instructions to participants to bind an O to the location in a working memory representation at which an X just appeared in a preceding prime. Participants might not have engaged in this additional coding spontaneously in Experiments 3a and 3b because of the effort required to do so, or perhaps the limited time to do so between prime and probe. We suspect that this additional coding might provide a basis for fluent integration of a probe O with a re-coded memory representation of the prime (i.e., fast performance), in contrast to the location-identity mismatch induced interference (i.e., slow performance) that occurred for such trials in Experiments 3a and 3b.

As noted above, we presume that the requirement to respond to the color of the prime X in Experiment 2a mitigated the partial match re-binding problem encountered in Experiments 3a and 3b. In this case, a strategic expectation favoring the location of the prime X might well lead to the maintenance of a representation in which the primary bound features were the expected location and the color of the stimulus that appeared at that location, rather than its identity. Since color information bound with the location-based expectation is irrelevant to the task of identifying and localizing the probe O, little interference would be generated. For this reason, aware participants in Experiment 2a may have had little trouble in using the contingency to facilitate their performance.

Conclusion

Taken together, our results suggest that explicit knowledge of statistical information in the environment depends upon multiple factors. Consistent with the results of Vaquero et al. (2010), selective attention can certainly influence awareness of contingencies between prime and probe in performance tasks like the one used here. Furthermore, our findings demonstrate that under certain circumstances, participants who are consciously aware of the contingency can use it strategically to facilitate performance, leading to the qualitative difference results observed in Experiment 2a. Yet the most intriguing finding reported here was that an appreciable number of participants appeared to be unaware of a strong contingency even when participants attended to and selected information that was directly related to the dimension on which the contingency was based. Only when bottom-up event integration processes allowed fluent integration between prime and probe did we witness levels of awareness consistent with our intuitions. Furthermore, strategic use of contingencies also appears to be limited by stimulus-response binding factors that affect the utility of strategic expectations to performance. The rich set of findings reported here suggests that the role of event integration on people's ability to detect trial to trial contingencies explicitly is a topic worthy of further research.

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Footnotes

[1] The interested reader may wonder whether the effect of Trial Type depended on whether or not the prime X appeared in one of the attended locations (vertical axis) or unattended locations (horizontal axis). To address this issue, we conducted a repeated-measures factorial ANOVA treating Trial Type (Location-change, Location-repeat/Identity-mismatch)[2] and Position (vertical/horizontal) as independent variables. The analysis revealed a main effect of Trial Type, $F(1, 16) = 36.3$, $p <.001$, and importantly, a significant interaction between Trial Type and Position, $F(1, 16) = 9.9$, $p <.01$. Further comparisons revealed that responses were slower to Location-repeat/Identity-mismatch trials than to Location-change trials, $t(16) = 6.0$, $p <.001$, but only when the prime X appeared in one of the two vertical locations. The effect of Trial Type did not reach significance when the prime X appeared in either horizontal location. This result is consistent with an IOR account which would predict slower responses for targets appearing in one of the two previously attended locations.

[2] We chose not to include the Location-repetition/Identity-match trials in our awareness analysis since these trials were not directly relevant to our main question of interest. Excluding these trials from the analysis simplifies our results section such that it contains only the most relevant information with regards to the specific question that we intended to address. However, for the interested reader, the mean RTs for these trials are given in Table 1 for all reported experiments.

Appendix

Upon completion of the experiment, participants were asked to answer the following questions in order to assess their explicit knowledge of the contingency.

1). What percentage of trials do you think were:

The X in the **first** display and the O in the **second** display were in the **same** position ___
The X in the **first** display and the O in the **second** display were in **different** positions___
= 100%

2). Did you use the first display to predict the location of the target (O) in the second display? (Y/N)

a) If not, why didn't you use it?

Table 1.
Mean correct RTs (in milliseconds) and high probability location repetition effects (LRE) for the Location-change (LC), Location-repeat/match (LR/IM), and Location-repeat/mismatch (LR/IMM) conditions, as a function of group (in Experiments 2a & b and 3). Participants were assigned to the Low accuracy group if they gave an estimate that was less than or equal to 50%, whereas they were assigned to the High accuracy group if they gave an estimate that was greater than 50%. Location repetition effects (LRE) that are statistically significant (p < .05) are indicated with an asterisk. The LRE for Experiments 1, 2a & b, 3 is for the Location-repeat/Identity-mismatch condition. The LRE for Experiment 4 is for the Location-repeat/Identity-match condition.

Experiment	N	Group	LC	LR/IM	LR/IMM	LRE
1	16		643	661	675	-32*
2a	10	Low (<=50)	471	467	483	-12*
	25	High (>50)	468	483	446	22*
2b	18		394	402	405	-11*
3a	7	Low (<=50)	464	484	497	-33*
	11	High (>50)	462	481	483	-21*
3b	26		442	434	441	1
	8	Low (<=50)	437	421	435	2
	18	High (>50)	444	440	443	1
4	12		439	405	462	34*

Table 2.
Percentage of errors and for the Location-change (LC), Location-repeat/match (LR/IM), and Location-repeat/mismatch (LR/IMM) conditions, as a function of group (in Experiments 2a,b and 3). Participants were assigned to the Low accuracy group if they gave an estimate that was less than or equal to 50%, whereas they were assigned to the High accuracy group if they gave an estimate that was greater than 50%.

Experiment	N	Group	LC	LR/IM	LR/IMM
1	16		1.3	1.4	2.2
2a	10	Low (<=50)	1.5	1.8	2.6
	25	High (>50)	2.0	3.5	2.2
2b	18		1.0	1.7	1.0
3a	7	Low (<=50)	3.4	3.7	3.7
	11	High (>50)	2.8	2.1	2.6
3b	8	Low (<=50)	2.1	1.7	3.7
	18	High (>50)	2.1	4.1	3.5
4	12		1.9	1.2	3.1

Table 3.
Comparison of awareness levels across experiments. The chi-square (X^2) values are those obtained from the comparison of Experiments 1-3 with Experiment 4. ***p <.001, *p <.05

Experiment	N	Aware	X^2
1	16	2	22.1***
2a	35	25	2.1
3a	18	11	3.9*
3b	26	18	2.4
4	24	21	--

Figure 1.

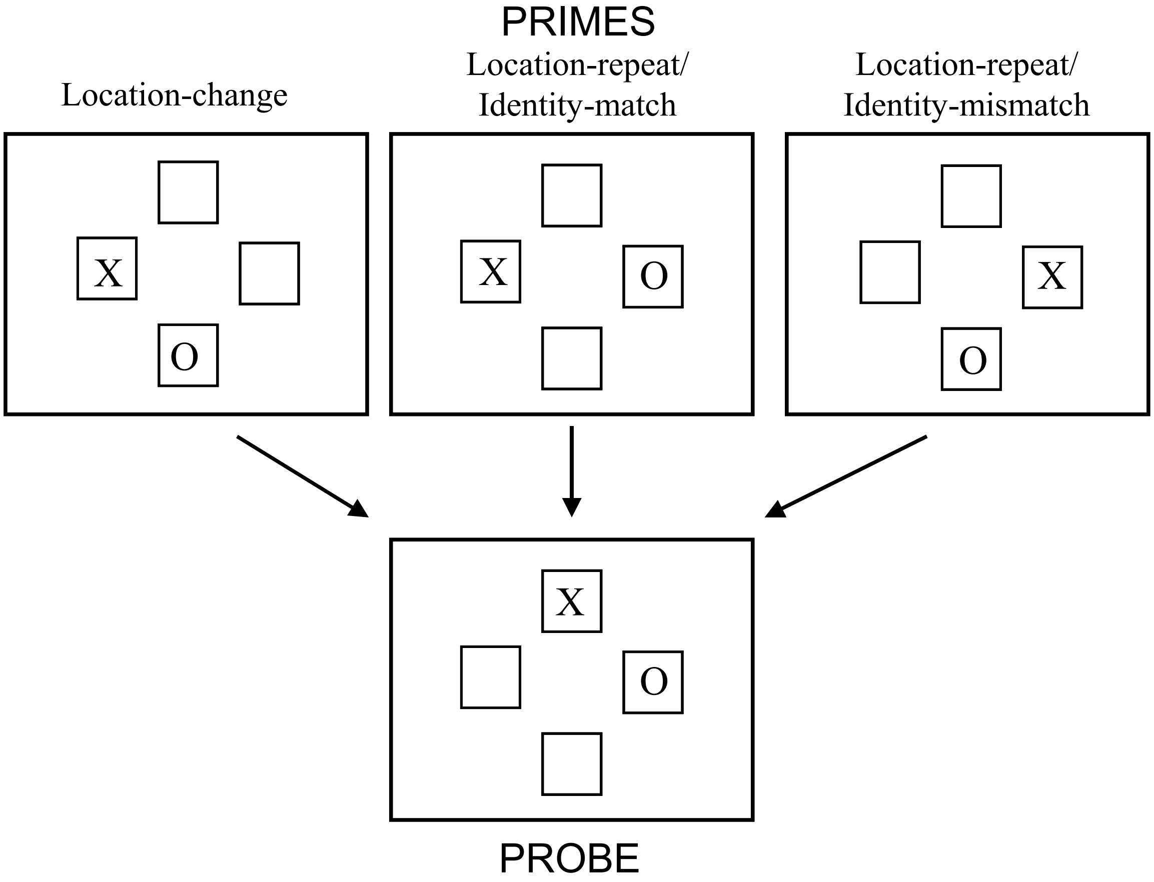
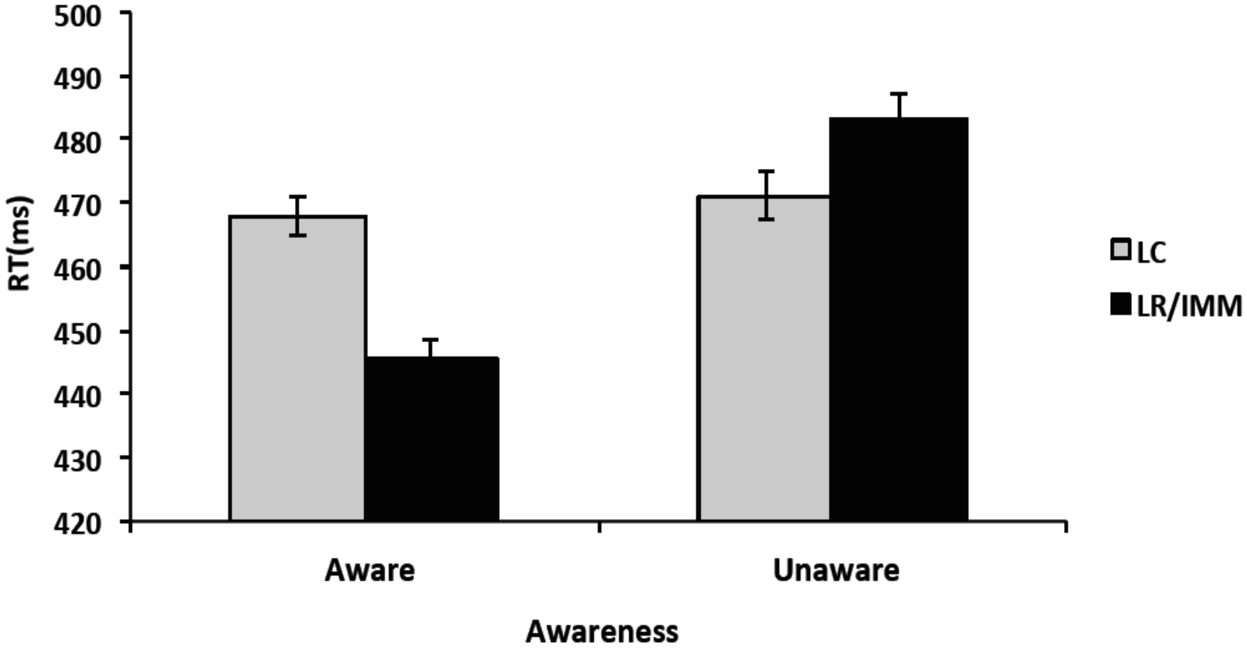

PRIMES
Location-change
Location-repeat/
Identity-match
Location-repeat/
Identity-mismatch
X
O
X
O
X
O
X
O
PROBE

Figure 2.



500
490
480
470
460
450
440
430
420
RT(ms)
Aware
Unaware
Awareness
LC
LR/IMM

Figure 3.

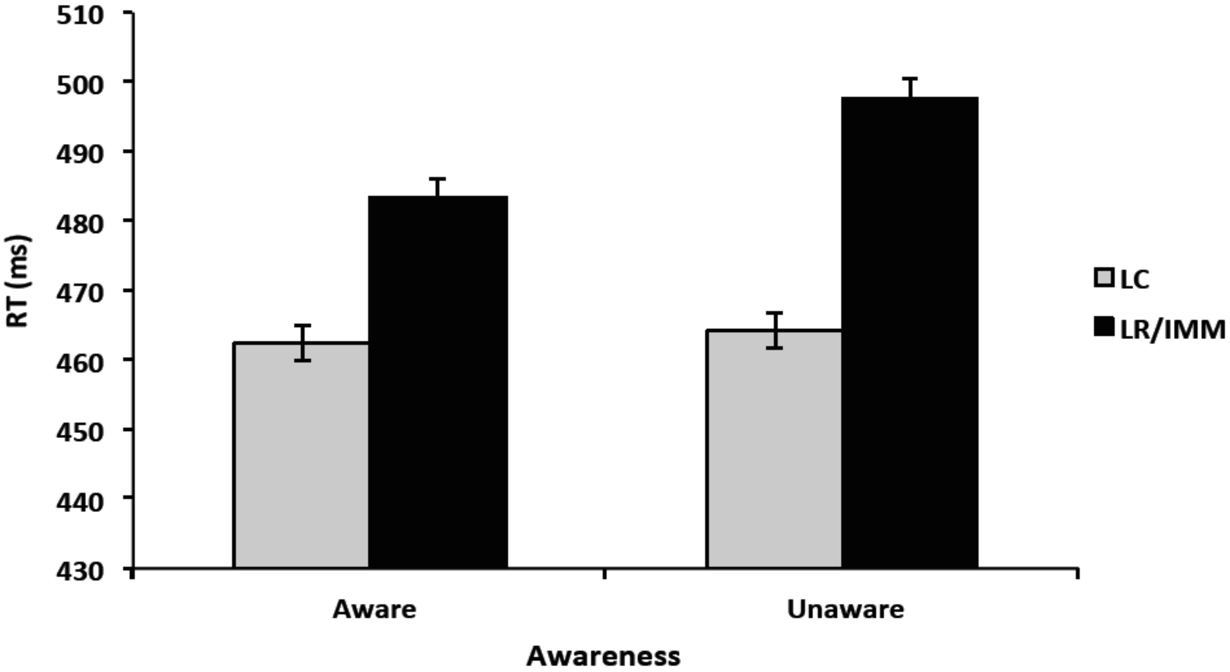
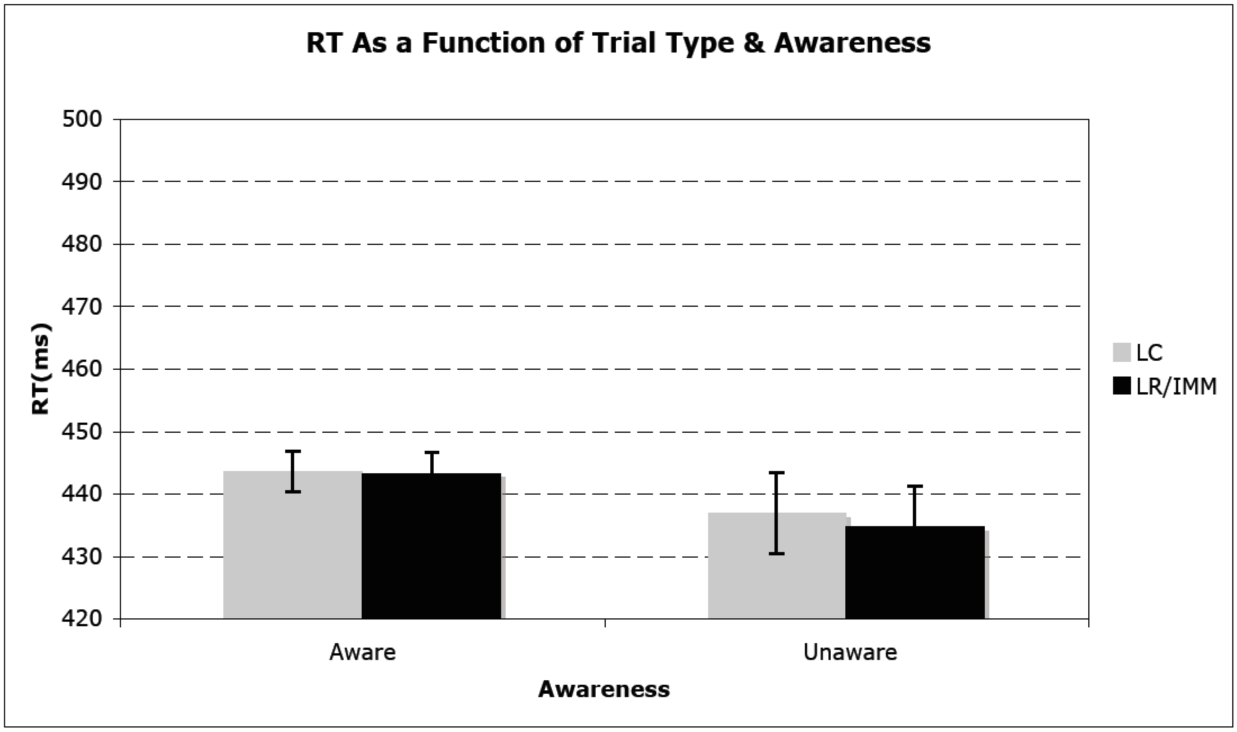

510
500
490
480
470
460
450
440
430
RT (ms)
Aware
Unaware
Awareness
LC
LR/IMM

Figure 4.


RT As a Function of Trial Type & Awareness
500
490
480
470
460
450
440
430
420
RT(ms)
Aware
Unaware
Awareness
LC
LR/IMM

CHAPTER 3: Contingency Blindness: Location-Identity Binding Mismatches Obscure Awareness of Spatial Contingencies and Produce Profound Interference in Visual Working Memory.

Fiacconi, C.M., & Milliken, B. (2012).

Memory & Cognition, 40, 932-945.

PREFACE

The experimental results reported in Chapter 2 strongly suggested that explicit awareness of contingencies in our task was primarily dependent upon the perceptual match/mismatch in feature bindings across successive visual displays. In particular, it was found that levels of explicit awareness were surprisingly low when participants were exposed to a contingency defined by a high proportion of trials on which there was a binding mismatch between the predictive item and the subsequent target item, and that this effect could not be attributed to inattention. Chapter 3 aimed to better understand why binding mismatches resulted in such profoundly low levels of contingency awareness. Experiment 1 constituted a replication of this basic finding, while Experiments 2a, and 2b confirmed that the local mismatch between the identity of the predictive item and subsequent target item was the critical factor in obscuring awareness, rather than mismatches in the global layout across the two displays. Having now established the importance of local binding mismatches in producing ‘contingency blindness,’ Experiment 3 focused on better understanding the mechanism by which these binding mismatches prevented participants from acquiring explicit awareness of contingencies in our task. Specifically, it was hypothesized that mismatches in location-identity bindings between two successive displays might impair memory for the feature bindings present within the first display, and that 'contingency blindness' might result from these mnemonic consequences. In support of this hypothesis, it was found that memory for the location of an item that was subsequently overlapped in space by a mismatching item was profoundly impaired. Importantly, however, this pattern of results was observed only when participants had to execute a localization response to the mismatching item in the second display. These findings support the idea that the mnemonic consequences of binding mismatches likely contribute to the observed 'contingency blindness' associated with these mismatches.

Abstract

The purpose of the present paper is to highlight the role of location-identity binding mismatches in obscuring explicit awareness of a strong contingency. In a spatial priming procedure we introduced a high likelihood of location-repeat trials. Experiments 1, 2a, and 2b demonstrated that participants' explicit awareness of this contingency was heavily influenced by the local match in location-identity bindings. In Experiment 3, we sought to determine why location-identity binding mismatches produce such low levels of contingency awareness. Our results suggest that binding mismatches can interfere substantially with visual memory performance. We attribute the low levels of contingency awareness to participants' inability to remember the critical location-identity binding in the prime on a trial-to-trial basis. Our results imply a close interplay between object-files and VWM.

Introduction

A great deal of research over the past two decades has focused on the construct of implicit learning. An often used procedure to study implicit learning exposes participants to a sequence of events that adhere to a systematic structure. This type of learning, referred to as *statistical learning*, has been demonstrated in a variety of tasks (Nissen & Bullemer, 1987; Chun & Jiang, 1998; Bartolomeo, DeCaix, & Sieroff, 2007; Turk-Browne, Junge, & Scholl, 2005; Fiser & Aslin, 2002; Baker, Olson, & Behrmann, 2004; Reber, 1967). For example, in sequence learning tasks, many studies have shown that people respond faster when targets follow a predictive sequence compared to when the sequence is random (Cohen, Ivry, & Keele, 1990; Nissen & Bullemer, 1987; Mayr, 1996). And yet, despite this sensitivity to sequential structure, many participants remain unable to describe verbally the relation between target locations. That is, they learn the structure implicitly, but not explicitly.

Although much has been learned from studies that examine the implicit learning of statistical structure, relatively little work has been directed at the question of how people learn and verbalize these statistical relations explicitly (but see Frensch, Haider, Runger, Neugebauer, Voigt, & Werg, 2002; Runger, & Frensch, 2008; Haider & Frensch, 2005). Indeed, the utility of consciousness as a construct in cognitive psychology has long been a contentious issue (see Holender, 1986; Marcel, 1983), and so one might argue that there is little need to study explicit learning separate from implicit learning. However, a compelling counter-argument is that there are a range of experimental contexts in which consciously aware and unaware states lead to opposite patterns of behavior (Cheesman & Merikle, 1986; Eimer & Schlaghecken, 2002; Vaquero, Fiacconi, & Milliken, 2010; Fiacconi & Milliken, 2011; Jimenez, Vaquero, & Lupianez, 2006; see Merikle, Smilek, & Eastwood, 2001 for a review). The fact that behavior can depend qualitatively on whether one is aware or unaware of a source of information suggests that consciousness is not merely an epiphenomenon, and that it merits study in its own right. With this issue in mind, the broad target of the current study was to examine the processes that affect explicit awareness of strong statistical relationships inherent in sequences of stimuli presented visually.

Our investigation stems from earlier work (Vaquero, Fiacconi, & Milliken, 2010; Fiacconi & Milliken, 2011) using a simple priming procedure. In these studies, we became interested in how reported awareness of a strong contingency mediates behaviour in a simple performance task. Participants were required to observe passively a prime stimulus containing two different letter characters appearing in two of four demarcated locations (see Figure 1 for a depiction of the various trial types). Following the prime, a probe display appeared and participants were instructed to localize a target character as fast as possible. A contingency was introduced such that the probe target letter (O) appeared in the same location as one of the two prime letters (either the X or O in separate experiments) on 75% of the trials. After the experiment was completed, participants were asked to report their subjective estimate of the percentage of trials in which this critical trial type occurred. Strikingly, when the identity of the predictive character in the prime mismatched the identity of the probe target (Location-repeat/Identity-mismatch trials), almost all participants were unable to verbalize the strong contingency that had been introduced (Experiment 1). However, when there was a match in identity (Location-repeat/Identity-match trials) between the predictive character in the prime and the probe target (Experiment 2), nearly all participants were able to verbalize the strong contingency accurately.

Initially, we suspected that the discrepancy between Experiments 1 and 2 of Vaquero et al. (2010) was due to participants paying attention and selecting the location of the O rather than the X in the prime display, despite the task not requiring participants to do so overtly (Folk, Remington & Johnston, 1992). In turn, attention to the prime O may have increased awareness of a strong contingency between the prime O and a probe O that was often in the same location (Experiment 2), but obscured awareness of a strong contingency between the prime X and a probe O that was often in the same location (Experiment 1). In effect, this idea assumes simply that inattention to a prime impedes the discovery of a strong contingency between that prime item and a following probe in the same location, much like inattention can impede conscious perception (see Mack & Rock, 1998).

However, follow-up work by Fiacconi and Milliken (2011) undermined this hypothesis. Participants in their study were instructed to select and process the contingency-relevant information in the prime in a variety of ways across a series of experiments. Although attention to the prime X did in some cases raise contingency awareness off the floor, a surprisingly large proportion of our participants again failed to notice the contingency. In fact, none of the attentional manipulations in those experiments led to contingency awareness comparable to that obtained when there was a match in identity between the probe target and the predictive character in the prime.

In light of these results, it seems likely that contingency awareness in this task is not dictated entirely by what one attends to, but rather is mediated by other processes that control how perceptual information is integrated with memory representations of recent prior experience. In particular, Kahneman, Treisman and Gibbs (1992) demonstrated that performance in a simple letter-naming task can depend on the efficiency with which current perception is integrated with an episodic memory representation, or object file, of a previous event. An object file refers to an updateable memory representation of the state of a perceptual object across space and time. The function of an object file is to maintain perceptual continuity as an object moves or changes in identity across time. New perceptual input can cue the retrieval of the contents of an object file if the new perceptual input shares the same spatiotemporal coordinates as the object file. If there is a good match in featural content between the new input and the retrieved object file, then a rapid *updating* process occurs by which the new information is integrated with information contained in the object file. If a poor match in featural content is found, the updating process occurs less efficiently. For example, in the Kahneman et al. (1992) study, participants were faster to name a probe letter when an identical preview letter had previously appeared in the probed location relative to when that preview letter had previously appeared in a different location.

The Kahneman et al. (1992) episodic integration framework can be applied in the current context as follows (see also Vaquero et al., 2010; Fiacconi & Milliken, 2011). For Location-repeat/Identity-match trials (see Figure 1), we often find that the match in featural content at the same location across the prime and probe trials results in fast performance, presumably because the probe is rapidly integrated with an existing object file. High levels of contingency awareness in this condition may then occur because the visual system treats the integrated prime and probe as one event, in effect enabling participants to “see” the relationship across trials. In contrast, for Location-repeat/Identity-mismatch trials (see Figure 1), the mismatch in featural content at the same location across the prime and probe stimuli typically results in slow performance. Low levels of contingency awareness in this condition might then be attributed to the visual system’s difficulty in treating the critical and prime and probes as one event, an interference effect that manifests in participants inability to "see" the strong contingency even across many trials.

In the present paper, we addressed two issues raised by application of the Kahneman et al. (1992) object integration framework to our prior results. First, although our prior work is consistent with the idea that location-identity binding processes (Kahneman et al., 1992) contribute to conscious awareness of spatial contingencies, the correspondence in spatial configuration across prime and probe displays could also play a significant role. In particular, note that for Location-repeat/Identity-mismatch trials (see Figure 1), the global configuration of elements within each display is not preserved across the prime and probe. Rather, the probe distractor X appears in a location that was not occupied in the preceding prime. As such, it remains possible that changes in spatial context at the global level, rather than mismatches in location-identity bindings at the local level, obscure awareness of the high likelihood of Location-repeat/Identity-mismatch trials. This issue is addressed directly in Experiments 2a and 2b.

Second, we examine more closely how location-identity bindings mediate contingency awareness. There are at least two different ways in which mismatches in location-identity bindings might disrupt contingency awareness. One possibility is that, upon post-experimental reflection, participants experience difficulty in recalling particular instances of location-identity mismatches, which in turn results in low 'awareness' of the contingency. In other words, mismatches in location-identity bindings could obscure awareness of the contingency by biasing participants' post-experimental decision processes. A second possibility is that location-identity mismatches could prevent participants from 'seeing' the relationship between the prime and probe on a trial-to trial basis. This issue is addressed in Experiment 3, in which we ask participants to remember prime items on every trial. To foreshadow the results, we find that location-identity mismatches produce a substantial interference effect in visual memory, a result that suggests there may be a close link between the dynamics of visual memory and explicit contingency awareness.

Experiment 1

The purpose of Experiment 1 was to replicate Experiment 1 of Vaquero et al. (2010). Recall that this experiment demonstrated a profound inaccuracy in the report of a strong contingency involving the Location-repeat/Identity-mismatch condition (see Figure 1). In this condition, the probe target O appears in the location of the prime X, while the probe distractor X appears in a new, previously unoccupied location. This experiment serves as a baseline to which later we compare the results of Experiments 2a and 2b.

Method

Participants. Sixteen undergraduate students from an introductory psychology course at McMaster University participated in exchange for course credit. The mean age of participants was 19.3 years. All participants had normal or corrected-to-normal visual acuity.

Apparatus and Stimuli. The experiment was carried out on a Pentium IBM compatible computer equipped with a NEC MultiSync colour monitor. Participants were seated approximately 40 cm from the monitor. Responses were made using a Gravis digital joystick that was interfaced to the computer via a standard game port. Response times were measured using the routines published by Bovens and Brysbaert (1990).

The stimuli in any given display appeared in two of four locations, marked by light grey boxes just above, below, left, or right of fixation. The boxes were positioned such that the horizontal visual angle between the centers of the left and right boxes was 5.0° and the vertical visual angle between the centers of the top and bottom boxes was 4.3°. Each box subtended a visual angle of 1.6° horizontally and 1.7° vertically. The letter O appeared in the center of one of the boxes and the letter X appeared inside another of the boxes in each stimulus display. Both letters were light grey and subtended 0.9° horizontally and 1.0° vertically.

Procedure and Design. Instructions appeared on the screen at the beginning of the experiment and were subsequently clarified by the experimenter to ensure that they were understood. Participants were told that an X and an O would each appear in two of the four boxes on both of two consecutive displays (see Figure 1). The task was to ignore the distracter letter X and indicate the location of the target letter O for the probe display only; no response was required for the prime display. Participants recorded their responses by moving a joystick in a direction that was spatially compatible with the location of the target (up, down, left, or right). Speed and accuracy of responses were both emphasized. Incorrect responses were indicated to the subject by a beep that sounded from the computer and responses that took longer than 3000 ms were also scored as incorrect.

Participants began each trial by depressing the start key on the joystick. The four location markers subsequently appeared on the screen and remained for the duration of the trial. One second after the onset of the location markers, the prime display appeared and remained on the screen for a duration of 157 ms. Following offset of the prime, there was a brief pause of 500 ms, followed by onset of the probe display. The probe display also remained visible for 157 ms. At this point, participants were to indicate the location of the target letter O with the appropriate joystick response. After each joystick response a brief 50 ms click was produced, which signaled to the participant that their response had been registered. A louder 'beep' was emitted if the participant responded incorrectly. After the participant responded to the probe display, the screen was cleared and a prompt appeared instructing the participant to begin a new trial.

There were two conditions tested in this experiment. In the Location-change condition both the O and X of the probe display appeared in locations that were unoccupied in the prime display. In the Location-repeat/Identity-mismatch condition, the O in the probe display appeared in the location occupied by the X in the prime display, while the X in the probe display appeared in an unoccupied prime location. The relative proportions of these two conditions were as follows: .75 Location-repeat/Identity-mismatch condition, and .25 Location-change condition. These relative proportions were achieved by including eighteen Location-repeat/Identity-mismatch trials, and six Location-change trials in each block of 24 trials.

Each participant completed a practice session in which the relative proportions of the two conditions were the same as in the test session, and in which they made a minimum of one correct response per condition, which resulted in a practice session of 24 trials for most participants. The test session consisted of 288 trials with a one-minute break at the end of every two blocks. When participants finished the task they were shown a drawing that depicted the two experimental conditions (Location-change and Location-repeat/Identity-mismatch), and they were required to estimate the percentage of trials that belonged to each of the conditions. Participants were also asked whether or not they used the prime to help them predict the location in which the probe target would appear.

Results

Response times (RTs) for correct trials in each condition (Location-change, Location-Repeat/Identity-mismatch) were first submitted to an outlier analysis that eliminated suspiciously short or long RTs (Van Selst & Jolicoeur, 1994). This procedure adjusts the cutoff criterion (in standard deviation units) as a function of sample size to prevent the systematic exclusion of different numbers of outliers from cells of different sizes. A total of 2.4% of trials were eliminated using this procedure. Mean correct RTs were then computed using the remaining observations, and these mean RTs and corresponding error percentages were compared using paired t-tests. Mean RTs in each condition, collapsed across participants, are displayed in Table 1. Corresponding error percentages for each condition are presented in Table 2.

Following our prior work using this procedure, we classified as "aware" participants who gave an estimate of the percentage of Location-repeat/Identity-mismatch trials that was greater than 50%. Only one of 16 participants was classified as aware of the contingency using this criterion, a result in line with that reported in prior studies (Vaquero et al., 2010; Fiacconi & Milliken, 2011). The mean estimate of the percentage of Location-repeat/Identity-mismatch trials was 34%. Only two participants reported using the prime to predict the location of the probe target. Because so few participants were classified as aware or strategic, the data from all participants were analyzed together in this experiment.

Paired t-tests indicated that responses to Location-change trials (452 ms) were faster than responses to Location-repeat/Identity-mismatch trials (472 ms), $t(15) = 6.0$, $p < .001$. The mean error rates for the two conditions did not differ significantly, $t(15) = .92$, $p = .37$.

Discussion

The results of Experiment 1 replicate those of Vaquero et al. (2010) and demonstrate the striking unawareness of participants to a strong inter-trial contingency. Although the probe target O appeared in the same location as the prime X on 75% of trials, this strong contingency went unreported, and presumably unnoticed, by most participants.

Another intriguing aspect of these results concerns the pattern of RTs. Although the strong contingency was not noted explicitly by most participants, one might reasonably expect participants would be sensitive to the strong contingency in the form of speeded responses to the trial type that occurred frequently. In other words, one might reasonably expect implicit learning of the contingency to occur despite the stark absence of explicit learning of that contingency. The finding that RTs were 20 ms slower for Location-repeat/Identity-mismatch trials (which occurred 75% of the time) relative to Location-change trials (which occurred 25% of the time) seems to contradict this idea. However, the experimental design used here does not allow us to measure sensitivity of the RTs to statistical contingencies, as there was no control condition in which the key statistical contingency was absent. This issue was addressed by Vaquero et al. (2010; Experiment 5) in an experiment that showed slower RTs to the frequent Location-repeat/Identity-mismatch condition than to the infrequent Location-change condition despite the presence of a learning effect that pushed this performance effect in the opposite direction. This result fits with the idea that two processes contribute to this behavioural effect, one that slows responses for the Location-repeat/Identity-mismatch condition and another that speeds responses for the Location-repeat/Identity-mismatch condition. The first of these processes might be related to the object-specific updating processes identified by Kahneman et al. (1992; see also Park &

Kanwisher, 1994)[1], while the second of these processes might reflect the implicit learning of statistical structure inherent in the trial sequence. The net result of these two processes would produce slow performance in the Location-repeat/Identity-mismatch condition if the object updating processes slow performance more than the implicit learning processes speed performance.

With this issue in mind, we do not dispute (and indeed expect) that implicit learning contributes to performance in this experiment. In particular, we propose that in the absence of explicit learning of the strong contingency, implicit learning influences on performance are often insufficient to override the more dominant object updating processes. We presume that it is these object updating processes that push performance in a direction that contradicts the statistical structure inherent in our design.

Experiments 2a and 2b

As pointed out in the Introduction, the "contingency blindness" observed in Experiment 1 could arise either from location-identity binding mismatches at the local level (the probe target O appearing in the location of the prime X), but could also arise from mismatches in the global spatial configuration of elements. Indeed, other work in the visual memory domain (Jiang et al. 2000; Simons, 1996) has pointed to global configuration as an important factor in allowing the visual system to link consecutive events together. In Experiments 2a and 2b, we examine these two competing hypotheses by manipulating the spatial configuration of display elements between the prime and probe. The trial types used in Experiments 2a and 2b are displayed in Figure 2. In Experiment 2a, our aim was to determine whether maintaining the global configuration of display elements between prime and probe raises the level of contingency awareness above that observed in Experiment 1. To address this issue, we replaced the Location-repeat/Identity-mismatch trials from Experiment 1 with 'Switch' trials in Experiment 2a. Note that for the Switch trial type, the global spatial configuration of display elements is preserved across prime and probe displays, while the local location-identity bindings are switched. In Experiment 2b, we replaced the Location-repeat/Identity-mismatch trials from Experiment 1 with 'Full Repetition' trials. Note that for the Full Repetition trial type, the global spatial configuration of display elements is preserved across prime and probe, as are the precise location-identity bindings. If mismatches in global spatial configuration were responsible for the low levels of awareness observed in Experiment 1, then we should observe near ceiling levels of awareness in both Experiments 2a and 2b. In contrast, if mismatches in location-identity bindings at the local level contribute to low levels of awareness, we should observe near ceiling levels of awareness in Experiment 2b but not in Experiment 2a.

Method

Participants. All 34 participants (16 in Experiment 2a, 18 in Experiment 2b) were McMaster University undergraduate students who participated in exchange for course credit. The mean age of participants was 19.7 years. All participants had normal or corrected-to-normal visual acuity.

Apparatus and Stimuli. These were the same as in Experiment 1.

Procedure and Design. These were the same as in Experiment 1 except that for Experiment 2a the Location-repeat/Identity-mismatch trials were replaced by Switch trials (see Figure 2). In the Switch condition, the probe target O appeared in the location of the prime X and the probe distractor X appeared in the location of the prime O. For Experiment 2b, the Location-repeat/Identity-mismatch trials were replaced by Full Repetition trials. In the Full Repetition condition, the probe target O appeared in the location of the prime O and probe distractor X appeared in the location of the prime X. The Location-change trials in both experiments were identical to those in Experiment 1.

To assess participants' explicit knowledge of the contingency, diagrams were given that depicted separately for each probe letter the prime letters that could have previously occupied the location of that probe letter (X, O, empty). Participants were then asked to indicate the percentage of trials for each of the depicted prime-probe letter combinations. For example, for the probe O, participants were asked to indicate the percentage of trials in which the location of the probe O was previously occupied by the prime X, the prime O, or was previously unoccupied. Participants were queried in this way to ensure that they were aware of the contingency at the local level. A subsequent question asked whether or not participants used the prime display strategically to predict the location of the probe target.

Results

Experiment 2a. Correct RTs were submitted to the same outlier elimination procedure as in Experiment 1, which eliminated 2.3% of the observations from further analysis. Mean RTs for each condition separated by reported awareness and strategy use are displayed in Table 1, and the corresponding error rates are shown in Table 2.

In this experiment, 7 out of 16 participants were classified as aware of the contingency. Although the number of participants classified as "aware" of the contingency in this experiment was greater than in Experiment 1, $X^2(1) = 4.17$, $p < .05$, there remained a large proportion of participants (.56) who remained unaware of the contingency. The mean estimate of the percentage of Switch trials for the aware participants was 67% whereas the mean estimate for the unaware participants was 36%. In addition, 9 of our participants reported using a strategy. Of these 9 participants, 7 belonged to the "aware" group while the remaining 2 participants belonged to the "unaware" group. We report the analyses of the RT data as a function of both awareness and strategy use below. Mean RTs can be found in Table 1.

A 2x2 mixed factor analysis of variance (ANOVA) treated Awareness (aware/unaware) as a between-subjects variable and Trial Type (Location-change/Switch) as a within-subjects variable. This analysis revealed no significant main effects of Awareness ($F < 1$), or Trial Type, $F(1, 14) = 1.95$, $p = .18$. The interaction between these variables also failed to reach significance, $F(1, 14) = 1.13$, $p = .31$. However, the mean RTs were generally in line with the idea that awareness of the strong contingency might induce use of a predictive strategy that speeds response for the relatively frequent Switch trials. To address this issue with more sensitivity, we then focused on participants' reports of strategy use.

A 2x2 mixed factor ANOVA treated Strategy Use (strategy/no-strategy) as a between-subjects variable and Trial Type (Location-change/Switch) as a within-subject variable. This analysis revealed a significant 2-way interaction, $F(1,14) = 9.2$, $p <.01$, and no main effect of either Strategy Use or Trial Type. To examine this interaction further, the effect of trial type was analyzed separately for the strategy and no-strategy groups. For the strategy group, responses to Switch trials (445 ms) were faster than responses to Location-change trials (485 ms), $t(8) = 2.4$, $p <.05$. In contrast, for the no-strategy group, responses to Location-change trials (453 ms) were faster than responses to Switch trials (471 ms), $t(6) = 5.1$, $p <.01$.

The mean error rates for each condition separated by awareness and strategy use are displayed in Table 2. For the error rate data separated by awareness, an ANOVA that corresponded to that conducted on the mean RTs revealed no significant effects (all *F*'s < 1). Likewise, for the error rate data separated by strategy use, a corresponding ANOVA revealed no significant main effects of either Strategy Use (*F* < 1), or Trial Type, *F*(1, 14) = 1.08, *p* = .32. The interaction between these variables also failed to reach significance (*F* < 1). For both aware/unaware and strategy/no-strategy analyses the pattern of error rates was consistent with the RT data, lending no support to a speed-accuracy trade-off interpretation of the RT results.

Experiment 2b. Correct RTs were submitted to the same outlier elimination procedure as in Experiment 1, which eliminated 2.2% of the observations from further analysis. Mean RTs for each condition are displayed in Table 1 and the corresponding error rates are shown in Table 2.

15 of 18 participants were classified as aware of the contingency. The proportion of aware participants in this experiment exceeded the proportion of aware participants in both Experiment 1, $X^2(1) = 17.23$, $p <.001$, and Experiment 2a, $X^2(1) = 4.21$, $p <.05$. The mean estimate of the percentage of Full Repetition trials was 67.5%. In addition, 14 of 18 participants reported using a strategy. Due to the small number of unaware/non-strategic participants, the RT data are reported collapsed across all participants.

The mean RTs for each trial type were compared using a paired t-test. This analysis revealed that responses to Full Repetition trials (357 ms) were faster than responses to Location-change trials (458 ms), $t(17) = 9.9$, $p <.001$.

An analysis of the error rates revealed that there were significantly more errors in the Location-change condition than in the Full Repetition condition, $t(17) = 4.35$, $p < .001$.

Discussion

Our primary aim in Experiments 2a and 2b was to explore the role of global spatial configuration and location-identity bindings in generating contingency awareness. Recall that in both experiments, the global configuration of display elements was maintained across both prime and probe. However, only in Experiment 2b were the local location-identity bindings preserved. If the low levels of contingency awareness in Experiment 1 were due to mismatches in global spatial configuration, then maintaining the global configuration of display elements should have produced near ceiling levels of awareness in both experiments. Conversely, if mismatches in location-identity bindings are critical to awareness, then near ceiling levels of awareness should be obtained in Experiment 2b but not in Experiment 2a. Our data are consistent with the latter hypothesis. Figure 3 summarizes the percentage of participants who were aware of the contingency in each of Experiments 1, 2a, and 2b. Although maintaining the global spatial configuration constant across prime and probe in Experiment 2a raised explicit contingency awareness relative to Experiment 1 (44% in Experiment 2a, 6% in Experiment 1), maintaining the location-identity bindings across prime and probe increased the number of aware participants by an additional 39%. This finding highlights the crucial role of repetition of location-identity bindings in generation of explicit awareness of a strong contingency in the present task context.

The RT results in this experiment are also noteworthy. The results of Experiment 2b were relatively straightforward, with faster responses for the Full Repetition condition than for the Location-change condition. Both the high percentage of Full Repetition trials and the fluent updating of the prime object (Kahneman et al., 1992) might well contribute to this effect. The results of Experiment 2a show a more striking pattern. Here, performance depended qualitatively upon reported strategy use. Participants who claimed not to use a predictive strategy were slower to respond to Switch trials than to Location-change trials. In contrast, participants who claimed to use a predictive strategy produced the opposite behavioural pattern, with faster responses for Switch trials than for Location-change trials. This pattern of data constitutes an example of a *qualitative difference* finding. As noted in the Introduction, qualitative differences have been useful in prior studies to distinguish between conscious and unconscious influences on behaviour (e.g., Cheesman & Merikle, 1986; Jacoby & Whitehouse, 1989). In our case, the presence of a qualitative difference indicates that participants who reported use of a strategy performed the task in a fundamentally different manner than participants who reported not using a strategy. Strong correlations between verbal report and behaviour can be quite rare (Nisbett & Wilson, 1977), and qualitative shifts in performance as a function of subjective verbal report are often difficult to measure in the laboratory. Although the processes that mediate the qualitative difference finding reported here are as yet unclear, we have found it a relatively straightforward effect to measure in the laboratory (see also Vaquero et al., 2010; Fiacconi et al., 2011).

Experiment 3

The results of Experiments 1, 2a, and 2b (see also Vaquero et al., 2010; Fiacconi & Milliken, 2011) provide strong support for the idea that contingency awareness is intimately linked to the object updating processes described by Kahneman et al. (1992). What is still unclear, however, is the mechanism by which mismatches in location-identity bindings obscure contingency awareness.

Our approach to answering this question was guided by some recent work in the visual memory literature. Traditional conceptions of visual memory distinguish between a brief, high capacity store known as *iconic memory* (Sperling, 1960; Averbach & Coriell, 1961), and a longer lasting, durable, low capacity store known as *visual working memory* (VWM, Phillips, 1974). The traditional view holds that representations in VWM are relatively durable, and resistant to masking, or interference from subsequent information. This characteristic of the VWM system, however, has been recently called into question (Alvarez & Thompson, 2008; Wheeler & Treisman, 2002; Allen, Baddeley & Hitch, 2006; Ueno, Allan, Baddeley, Hitch, & Saito, 2010; Sligte, Scholte, & Lamme, 2008; Makovski, Sussman, & Jiang, 2008; Makovski, Watson, Koutstaal, & Jiang, 2010; Landman, Spekreijse, & Lamme, 2003). These studies have shown that representations in VWM are indeed quite vulnerable to subsequent interference. Furthermore, there is evidence to suggest that bound featural information is particularly susceptible to interference in the absence of attention (Wheeler & Treisman, 2002; but see Johnson, Hollingworth, & Luck, 2008).

Given the recent work in the visual memory domain, it is possible that the profound contingency blindness we have measured in prior studies occurs because processing of the probe interferes with the ability to retrieve a visual memory representation of the prime. By this view, participants' inability to accurately verbalize the contingency would reflect the cumulative result of many trials in which visual memory interference made participants unaware of the location repetitions as they happened. If one assumes that mismatches in location-identity bindings are a potent source of interference, then it follows that contingency awareness would be low when these mismatches are present but high when mismatches are absent, as reported by Vaquero et al. (2010). Indeed, such an account would highlight an interesting relationship between object file updating and visual memory.

The general procedure in Experiment 3 was similar to that of Experiments 1, 2a and 2b, with the addition of a memory test after the probe display on each trial. Participants were instructed that their memory for the location of one of the two prime letters would be tested on each trial following the probe display. Participants did not know at the beginning of each trial which of the two prime letters would be tested, and therefore successful performance required participants to remember the location-identity bindings for both prime letters. This design enabled us to assess memory accuracy for location-identity bindings as a function of different prime-probe configurations. The key question concerned whether interference would be maximal for Location-repeat/Identity-mismatch trials. Furthermore, to assess the importance of responding to the probe display in producing such an interference effect, two groups of subjects were tested, one that was instructed to respond to the location of the probe target and then also to remember the location of one of the two primes (Probe Response group), and one that was instructed simply to observe the probe display prior to remembering the location of one of the two primes (No Probe Response group).

Method

Participants. 22 undergraduate students from an introductory psychology course at McMaster University participated in exchange for course credit. The mean age of participants was 18.6 years. All participants had normal or corrected-to-normal visual acuity. Half of the participants were randomly assigned to the No Probe Response group while the other half were assigned to the Probe Response group.

Apparatus and Stimuli. These were the same as in Experiments 1, 2a, and 2b.

Procedure and Design. The overall structure of Experiment 3 was similar to Experiments 1, 2a and 2b with a few exceptions. The trial sequence for Experiment 3 is depicted in Figure 4. In addition to a prime and probe display, participants were given a test display following the probe. In the test display, the four potential target locations were numbered 1-4 and a memory cue, either an X or an O, appeared in the center of the screen. In the memory component of the task, participants were to indicate the location in the prime display that was occupied by the letter indicated by the memory cue presented at the end of the trial. Overall, the procedure was as follows for the two groups.

For the No Probe Response group, the prime display appeared for 157 ms, and participants were instructed to remember the location of both the X and the O. Participants were told that at the end of each trial they would be asked to indicate the location of one of the two letters but were not told in advance which letter would be tested. Following an inter-stimulus interval (ISI) of 500 ms, the probe display appeared for 157 ms and participants were instructed to pay attention but not to respond to this display. Three different trial types were used in this experiment: Location-change, Location-repeat/Identity-mismatch, and Location-repeat/Identity-match (see Figure 1). The proportions of trials for the three trial types were equal (.33). Following a 700 ms ISI, the test display appeared. Participants indicated where they thought the cued letter had appeared during the prime display by pressing keys 1-4. Memory for each of the two letters (X and O) was tested equally often across the experiment. Responses to the test display were not speeded, but participants were instructed to try to respond within three seconds. After response to the test display, the screen cleared and the next trial began. Each trial was self-paced and participants pressed the space bar to begin the next trial.

For the Probe Response group, the procedure was much the same except that participants were instructed to localize and respond to the target letter O in the probe. Participants made their responses to the probe using a keyboard where 'W' mapped onto the top location, 'S' mapped onto the bottom location, 'J' mapped onto the left location, and 'K' mapped onto the right location. The test display appeared immediately after the probe response. Upon onset of the test display, participants in the Probe Response group used the same keys (W, S, J, K) to indicate their response to the memory task.

As such, Experiment 2 consisted of a 2 (Probe Response/No Probe Response) x 3 (Location-change, Location-repeat/Identity-mismatch, Location-repeat/Identity-match) x 2 (Memory Cue X/O) factorial design.

Results

The key dependent variable in this experiment was the proportion of responses in which participants correctly indicated where the cued letter had appeared during the prime display. For the Probe Response group, trials in which participants made an incorrect localization response to the probe target were excluded from our analysis. The mean localization error rates were 6.0%, 11.5%, and 5.3% for Location-change, Location-repeat/Identity-mismatch, and Location-repeat/Identity-match trials, respectively. The mean proportion of correct responses for each condition can be found in Figure 5.

The proportions of correct responses in each condition were submitted to a mixed factor ANOVA that treated Response (Probe Response/No Probe Response) as a between-subject factor, and Trial Type (Location-change, Location-repeat/Identity-mismatch, Location-repeat/Identity-match) and Memory Cue (X/O) as within subject factors[2]. This analysis revealed a significant main effect of Response, $F(1, 20) = 18.6$, $p< .001$, $\eta_p^2 = .48$, indicating that memory accuracy was poorer in the Probe Response group than in the No Probe Response group. However, of most importance is the significant 3-way interaction between Response, Trial Type, and Memory Cue, $F(2, 40) = 33.6$, $p< .001$, $\eta_p^2 = .63$ To examine this interaction further, the effects of Trial Type and Memory Cue were analyzed separately for each group.

For the No Probe Response group, a 2 (X/O) x 3 (Location-change, Location-repeat/Identity-mismatch, Location-repeat/Identity-match) mixed factorial ANOVA revealed no significant main effects of either variable, nor was there a significant interaction.

For the Probe Response group, however, there was a significant interaction between Trial Type and Memory Cue, $F(2, 20) = 42.5$, $p< .001$, $\eta_p^2 = .81$. To examine this interaction further, three separate t-tests were conducted comparing the effect of Memory Cue at each level of Trial Type. For the Location-change trials, this contrast compares memory performance for the prime X and prime O when neither of these letters are superimposed by a following probe item. In this case, there was no difference in memory performance for the X and O ($p > .1$). For the Location-repeat/Identity-match trials, this contrast compares memory performance for the prime X when it was not superimposed by a following probe item with memory performance for the prime O when it was superimposed by an identical probe O. Again, there was no difference between these two conditions ($p > .3$). Finally, for the

Location-repeat/Identity-mismatch trials, this contrast compares memory performance for the prime X when it was superimposed by a probe target O with memory performance for the prime O when it was not superimposed by a following probe item. Here, there was a strong effect of Memory Cue, $t(10) = 8.6$, $p < .001$, with much poorer accuracy when participants were asked to remember the location of the prime X as opposed to the prime O.

We also analyzed the probe localization RT data for the Probe Response group. Correct RTs were submitted to the same outlier procedure as in Experiment 1 resulting in the elimination of 1.5% of trials. Mean RTs were then calculated for each trial type (see Table 1) and then submitted to a one-way ANOVA treating Trial Type as a within-subjects variable[2]. This analysis revealed no significant main effect of Trial Type, $F(2, 20) = 1.86$, $p = .18$.

Discussion

The goal of Experiment 3 was to examine memory performance on a trial-to-trial basis for the critical condition (Location-repeat/Identity-mismatch) that produced profoundly low contingency awareness in Experiments 1 and 2a. We were particularly interested in the possibility that memory performance would be selectively poor in this condition. The results of Experiment 3 revealed just such an effect. Memory performance for the critical condition in which participants were asked to indicate the location of the prime letter (X) that was subsequently replaced by the probe target (O) was very poor; indeed the mean proportion correct (.28) was not much better than chance performance of .25. Although this experimental design did not include a contingency favoring Location-repeat/Identity-mismatch trials (and therefore did not allow us to measure contingency awareness), it is tempting to conclude that the poor contingency awareness in Experiment 1 and the poor memory performance in this experiment are related – that is, location-identity binding mismatches interfere profoundly with visual memory, which may in turn result in profoundly low contingency awareness.

The results of Experiment 3 also suggest that interference due to binding mismatches is not an obligatory process – rather it seems to occur only when selective attention is needed to direct some form of action/response to the mismatching stimulus. Whether the *re-binding* of a new stimulus to a previously occupied location through an overt response is crucial to the effect observed here is an important question for further research.

General Discussion

The results of Experiments 1, 2a, and 2b, provide strong evidence that awareness of contingencies in the present task context depends on the match in location-identity binding at the local, contingency-relevant locations. The results of Experiment 3 provide compelling evidence that mismatches in location-identity bindings can produce mnemonic interference when participants must re-bind a new identity to a previously occupied location. Together, these results point to a potential relation between object file updating, VWM, and explicit contingency awareness. By this view, basic cognitive mechanisms that bridge the past may be a general principle that mediates explicit learning of statistical redundancies.

The Specificity of Contingency Blindness

A central claim here is that explicit awareness of spatial contingencies in the present task context is obscured when the critical contingency involves integration of two stimuli that mismatch in their location-identity bindings. However, a related question concerns the mechanisms that support explicit awareness of spatial contingencies more generally. Although participants were unable to verbalize the specific nature of the contingency in Experiment 1, participants nonetheless may have acquired some explicit awareness of general spatial redundancies in our task. For instance, participants might have been aware that the probe O frequently appeared in a location that was previously occupied in the prime display, although they may not have known what identity occupied that prime location. Although this was not the issue of primary interest in our study, some of our data speak to this question as well.

Recall that in Experiment 1, our questionnaire asked participants to give an estimate of all possible combinations of prime-probe sequences. If it were the case that participants were aware of spatial redundancies between the prime and probe but not of the specific location-identity bindings, then in the post-experimental questionnaire one would expect that participants should, on average, estimate an equal number of trials in which the probe O appeared in the same location as the prime O, and in which the probe O appeared in the same location as the prime X. In effect, participants would be guessing as to which particular letter had appeared in the location of the probe O. Our data are inconsistent with this hypothesis. For the 11 unaware participants in Experiment 1, the mean estimate of the proportion of trials in which the probe O followed in the same location as the prime X was .33. In contrast, the mean estimate for the proportion of trials in which the probe O followed in the same location as the prime O (this, of course, never actually happened in Experiments 1 or 2a) was .08. This pattern also held true for the 9 unaware participants in Experiment 2a. These data suggest that participants in our experiments who were unaware of the specific contingency defined by mismatches in location-identity bindings were also unaware of frequent identity-nonspecific location repetitions.

Interference or Backward Masking?

We have thus far interpreted the inability of participants to remember the location of the prime X after responding to Location-repeat/Identity-mismatch trials as reflecting interference in visual memory caused by the mismatch in location-identity bindings. However, an alternative explanation could be that poor memory accuracy in this condition reflects a form of *backward masking* whereby the onset of the probe stimulus disrupts or destroys any perceptual representation of the critical prime stimulus at the superimposed location. By this view, poor memory performance for the critical prime stimulus is a consequence of impoverished perceptual data rather than a result of competing representations in visual memory. There is, however, good reason to doubt that this is the case. The SOA between the prime stimulus and the probe stimulus was 657 ms – well outside the typical time course of backward masking effects (Breitmeyer, 1984; Vogel, Woodman, & Luck, 2006). Indeed, Vogel and colleagues (Vogel et al., 2006) estimate that the rate at which people can form a durable representation of a stimulus in visual memory is approximately 50 ms per item (the rate of consolidation has been estimated by others to be as fast as 20-30 ms per item; see Gegenfurtner, & Sperling, 1993). Given this rate of consolidation and the fact that the prime contained only two items, both prime items should have been consolidated into a durable working memory representation even before the start point of the ISI. Therefore, it is unlikely that the onset of the probe disrupted the sensory encoding of the prime stimuli prior to their consolidation.

A related concern might be that efficient consolidation of items into working memory may depend on the availability of central attentional resources (Jolicoeur & Dell'Acqua, 1998; Chun & Potter, 1995). Recall that for the Probe Response group in Experiment 2, participants were required to respond as quickly and as accurately as possible to the location of the probe target (O). One could conceive of this process as requiring the central attentional resources that are necessary to consolidate the prime characters into VWM. If such central resources are unavailable to transfer the initial, fragile representations of the prime items, then poor memory performance could reflect poor encoding as opposed to interference.

However, there is good reason to doubt this explanation. The requirement to respond to the probe target in Experiment 3 did not result in a uniform drop in memory accuracy across all conditions. While overall memory accuracy was worse for the Probe Response group, responding to the probe target disproportionately affected memory performance when participants were asked to remember the location of an object that was replaced by a new, different object (the prime X in Location-repeat/Identity-mismatch trials). It seems unlikely that disrupting central encoding mechanisms via preparing and executing a response would affect consolidation for just one of the prime items. Recall that memory performance for the location of the prime O was quite good on Location-repeat/Identity-mismatch trials. The results from Experiment 3, then, are more consistent with a location-identity binding interference interpretation, as opposed to a central capacity-limited encoding interpretation.

The Relationship Between Object Files and VWM

The results of Experiment 3 suggest a close tie between processes related to object file updating and the contents of VWM. Specifically, when participants were required to re-bind a new identity to the spatiotemporal coordinates of a previous different identity (Location-repeat/Identity-mismatch trials), they could no longer remember the location in which the initial object had appeared. It was almost as if binding an overt response toward a new identity in an old location forcefully updated the memorial representation of the contents of that location to reflect the new identity, overwriting the previous content. Such an interpretation makes good sense if one considers the purpose of object files. Object files serve the purpose of temporarily representing perceptual information in order to establish continuity with new incoming information on the basis of spatiotemporal coherence. By this view, object files must be continuously updated to reflect the current state of the world. Once updated, the previous contents of an object-file would be of little value (for related empirical work, see Kahneman et al., 1992; Alvarez & Thompson, 2008; Wheeler & Treisman, 2002; Allen, Baddeley & Hitch, 2006; Makovski, Sussman, & Jiang, 2008; Makovski, Watson, Koustaal, & Jiang, 2010).

An important question, then, is whether object files constitute the representational format of VWM. This question was addressed in a recent paper by Hollingworth and Rasmussen (2010). These authors combined the object reviewing paradigm developed by Kahneman et al. (1992) with a change detection task in order to assess whether VWM is sensitive to object updating processes. Their results suggested that representations in VWM exhibit some properties of object files, but that VWM can also store information in a scene-based representational format, and that therefore VWM representations are not necessarily object-based. Nonetheless, our results are consistent with the idea that object files and VWM representations can have similar properties. Further work on this important issue is certainly needed.

Implicit Learning in the absence of explicit learning?

While our focus in this paper has been on the factors that influence explicit learning of spatial contingencies, there is plenty of research demonstrating that people can exhibit implicit sensitivity to statistical redundancies (Nissen & Bullemer, 1987; Chun & Jiang, 1998; Bartolomeo, DeCaix, & Sieroff, 2007; Turk-Browne, Junge, & Scholl, 2005; Fiser & Aslin, 2002; Baker, Olson, & Behrmann, 2004; Reber, 1967). Perhaps of most relevance to the current paper are those studies that have demonstrated sensitivity to the statistical structure of sequences of visual shapes (Turk-Browne, Junge, & Scholl, 2005; Fiser & Aslin, 2002; Baker, Olson, & Behrmann, 2004). Known as *visual statistical learning*, such sensitivity has been well documented despite the absence of explicit knowledge regarding the relationships between shapes. Fiser et al. (2002) familiarized participants with sequences of shape triplets and demonstrated that people were sensitive to the greater joint probability of shapes within a triplet versus a shape sequence composed of non-triplet elements. Such learning took place even though participants were instructed to simply observe the sequence of shapes without any overt task per se.

Given this and other demonstrations of implicit sensitivity to the statistical structure of visual information, one might expect participants to have learned implicitly the contingency present in Experiments 1 and 2a despite an absence of explicit knowledge of this regularity. As noted earlier in the article, this result has been observed and reported in prior work with this procedure (Vaquero et al., 2010). Under conditions in which participants failed to note the presence of a strong contingency favoring Location-repeat/Identity-mismatch trials, they nonetheless demonstrated a sensitivity to this probabilistic structure in their behavioural performance. As such, we do not dispute that implicit statistical learning contributes to performance in the present task context, and we emphasize that our conjecture regarding the role of location-identity binding mismatches in contingency learning is intended to explain only the patterns of learning that are expressed in participants' explicit subjective reports.

Conclusion

The research reported here points to the possibility that the relation between event integration processes and explicit learning of contingencies is mediated by visual working memory. By this view, strong statistical relationships between events unfolding over time can be obscured from awareness when binding mismatches prevent the fluent integration of current perceptual information with representation of recent prior experiences. Although we are aware that our results do not require this interpretation, and that both low levels of awareness (Experiment 1) and poor memory performance (Experiment 3) for location-identity binding mismatches may be co-incidental, the possibility that these two results are related seems a compelling issue to pursue in future studies. The unique contribution of the present paper is to point to the potential relation between these two results, and thereby highlight a tool for studying performance, the dynamics of visual memory, and the contents of awareness.

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Footnotes

[1] Although we have suggested that an inefficient object-updating process might be responsible for slowing performance on Location-repeat/Identity-mismatch trials, another process which has been shown to operate in similar contexts is one that produces that the inhibition of return (IOR) effect. This process serves to slow responding toward locations that were previously occupied, irrespective of matches in featural content between those locations (Milliken, Tipper, Houghton, & Lupianez, 2000; Christie, & Klein, 2001). An in-depth discussion on the relative contribution of these two processes to performance is outside the scope of the present paper, but we note that both processes may influence performance in our task.

[2] In cases where violations of sphericity were present, degrees of freedom were adjusted using the Huynh-Feldt correction.

Table 1.
Mean correct RTs (in milliseconds) as a function of Trial Type for Experiments 1, 2a, 2b, and 3. For Experiment 2a, RTs were separated by reported awareness and reported strategy use. Participants were classified as aware of the contingency if they gave an estimate of the proportion of Switch trials greater than 50%. Participants were classified as strategic if they reported using the prime stimulus to predict the location of the probe target (O). RTs for Experiment 3 are for the Probe Response group only.

Experiment	N	LC	LR/IMM	LR/IM	Switch	Full Repetition
1	16	452	472	-	-	-
2a (Unaware)	9	457	-	-	453	-
2a (Aware)	7	489	-	-	460	-
2a (No Strategy)	7	453	-	-	471	-
2a (Strategy)	9	485	-	-	445	-
2b	18	458	-	-	-	357
3	11	1300	1305	1222	-	-

Table 2.
Percentage of errors as a function of Trial Type for Experiments 1, 2a, 2b, and 3. For Experiment 2a, RTs were separated by reported awareness and reported strategy use. Participants were classified as aware of the contingency if they gave an estimate of the proportion of Switch trials greater than 50%. Participants were classified as strategic if they reported using the prime stimulus to predict the location of the probe target (O). Error rates for Experiment 3 reflect localization errors for the Probe Response group.

Experiment	N	LC	LR/IMM	LR/IM	Switch	Full Repetition
1	16	.96	1.2	-	-	-
2a (Unaware)	9	1.2	-	-	.83	-
2a (Aware)	7	1.8	-	-	1.3	-
2a (No Strategy)	7	1.9	-	-	1.0	-
2a (Strategy)	9	1.4	-	-	1.1	-
2b	18	3.2	-	-	-	.29
3	1	6.0	11.5	5.3	-	-

Figure 1.

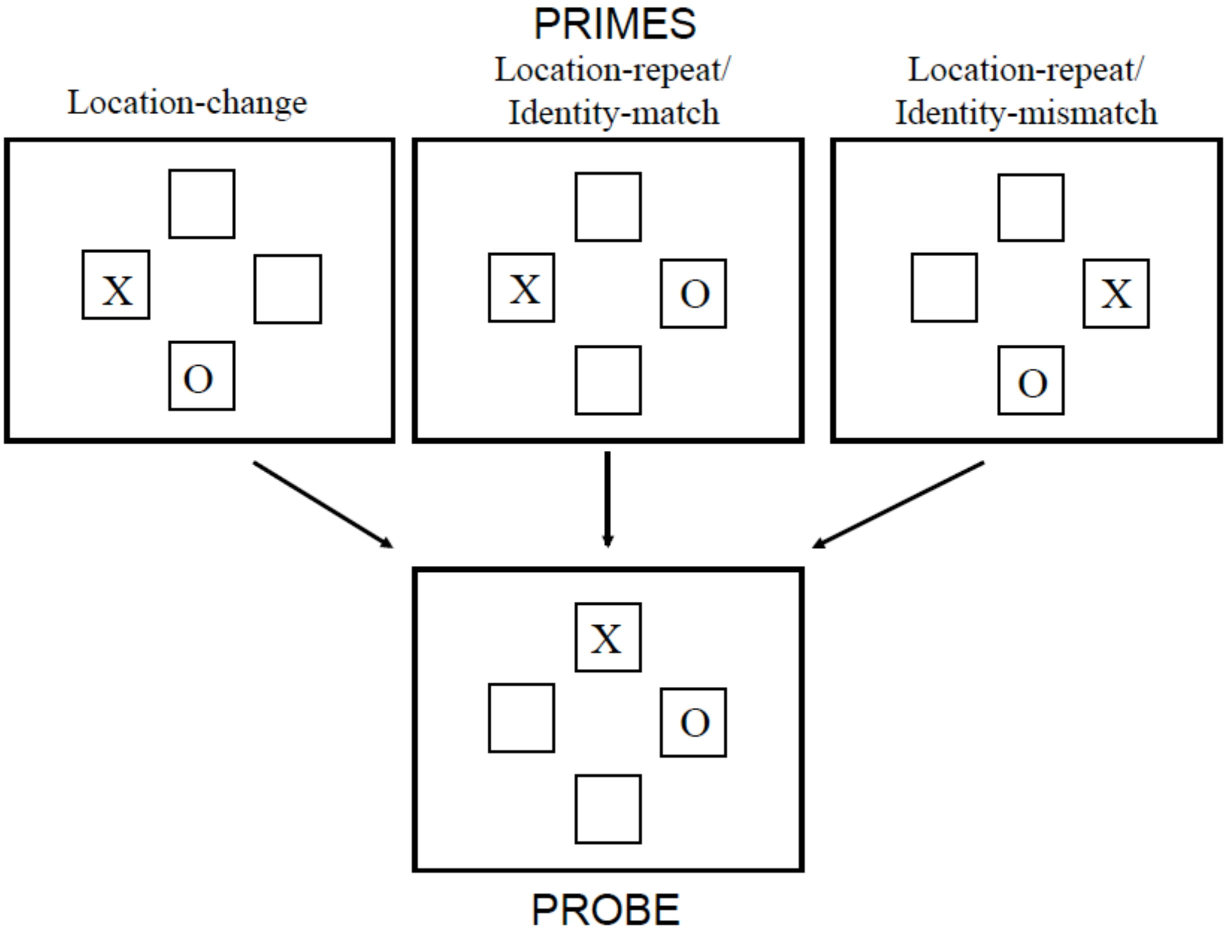

PRIMES
Location-change
Location-repeat/
Identity-match
Location-repeat/
Identity-mismatch
X
O
X
O
X
O
X
O
PROBE

Figure 2.

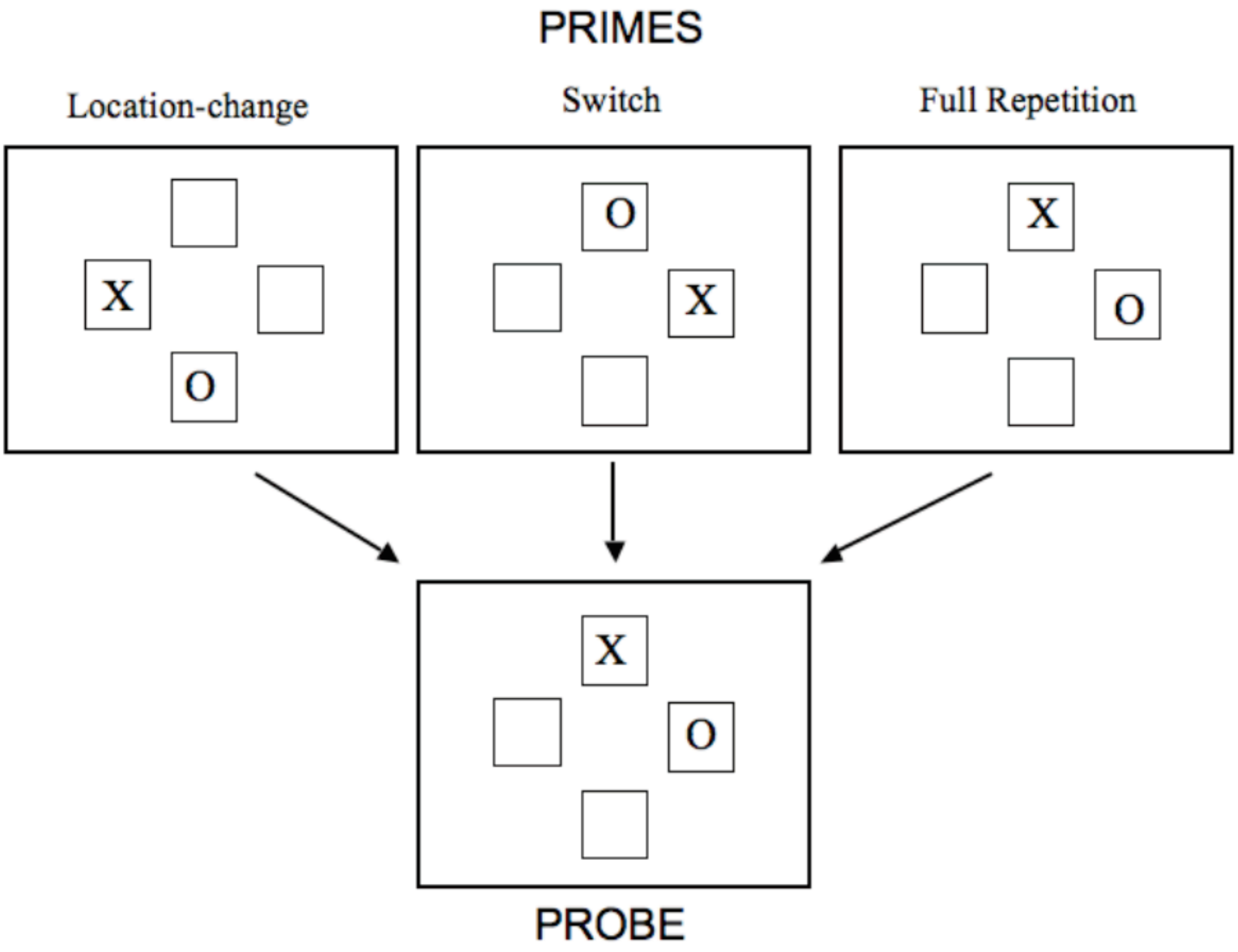

PRIMES
Location-change
Switch
Full Repetition
X
O
O
X
X
O
X
O
PROBE

Figure 3.

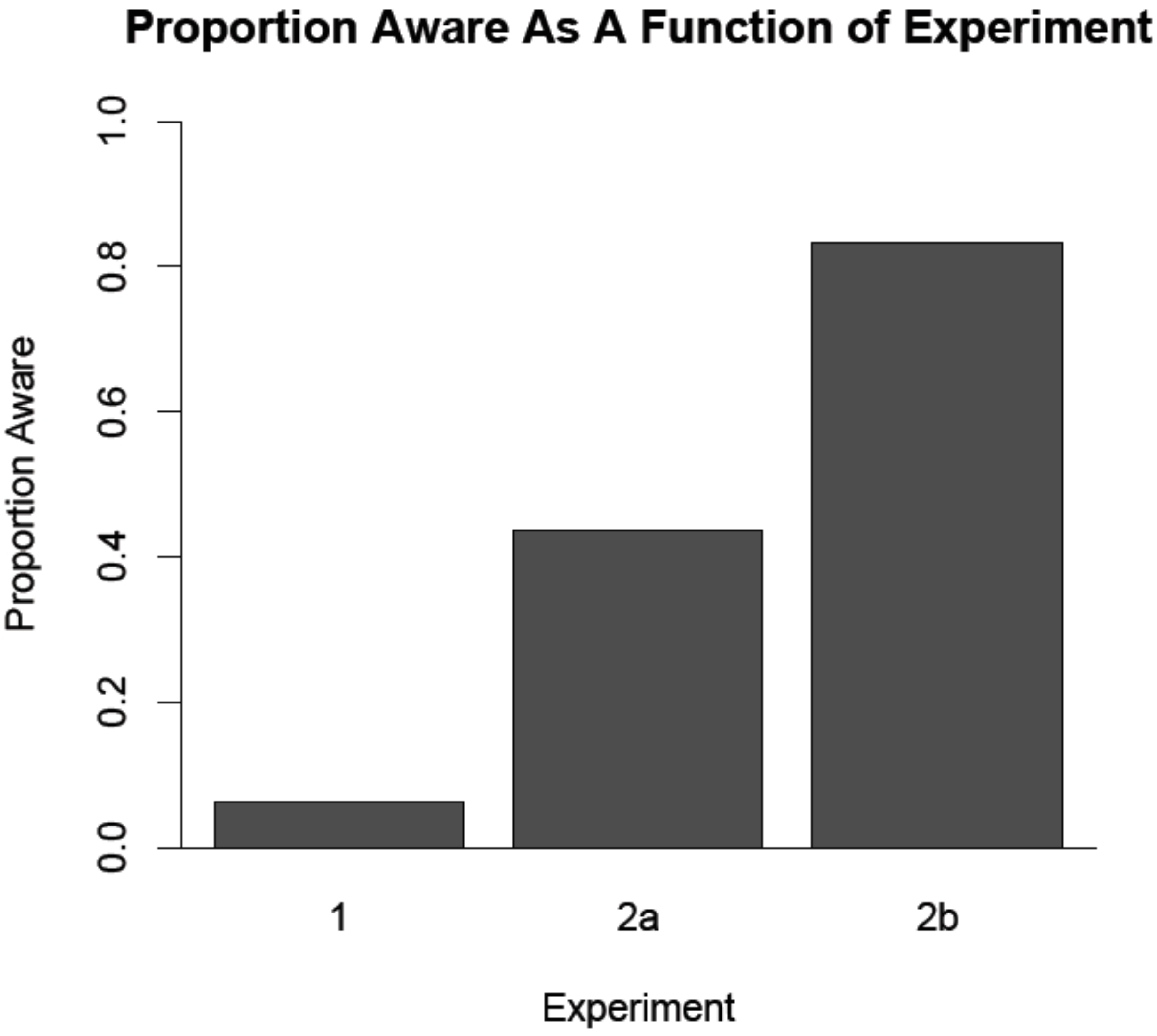

Proportion Aware As A Function of Experiment
Proportion Aware
0.0
0.2
0.4
0.6
0.8
1.0
1
2a
2b
Experiment

Figure 4.

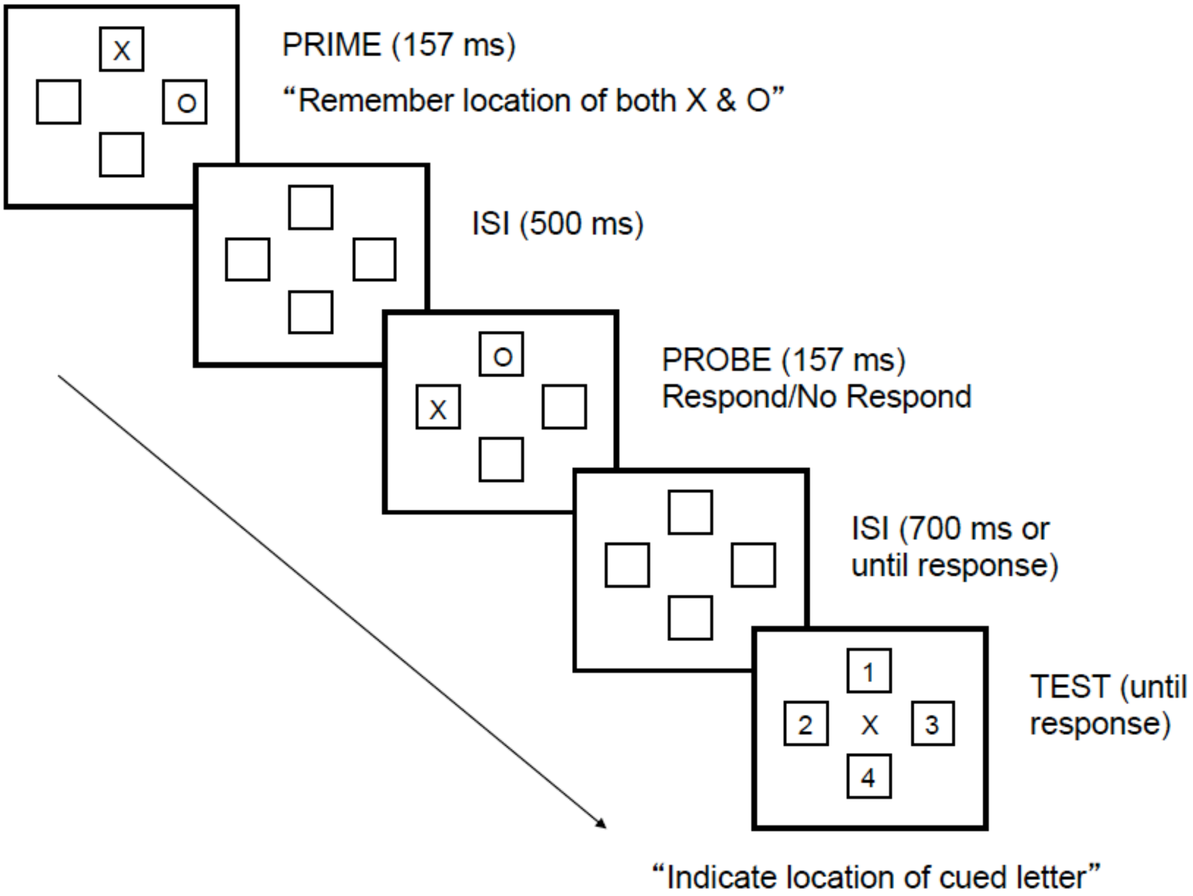
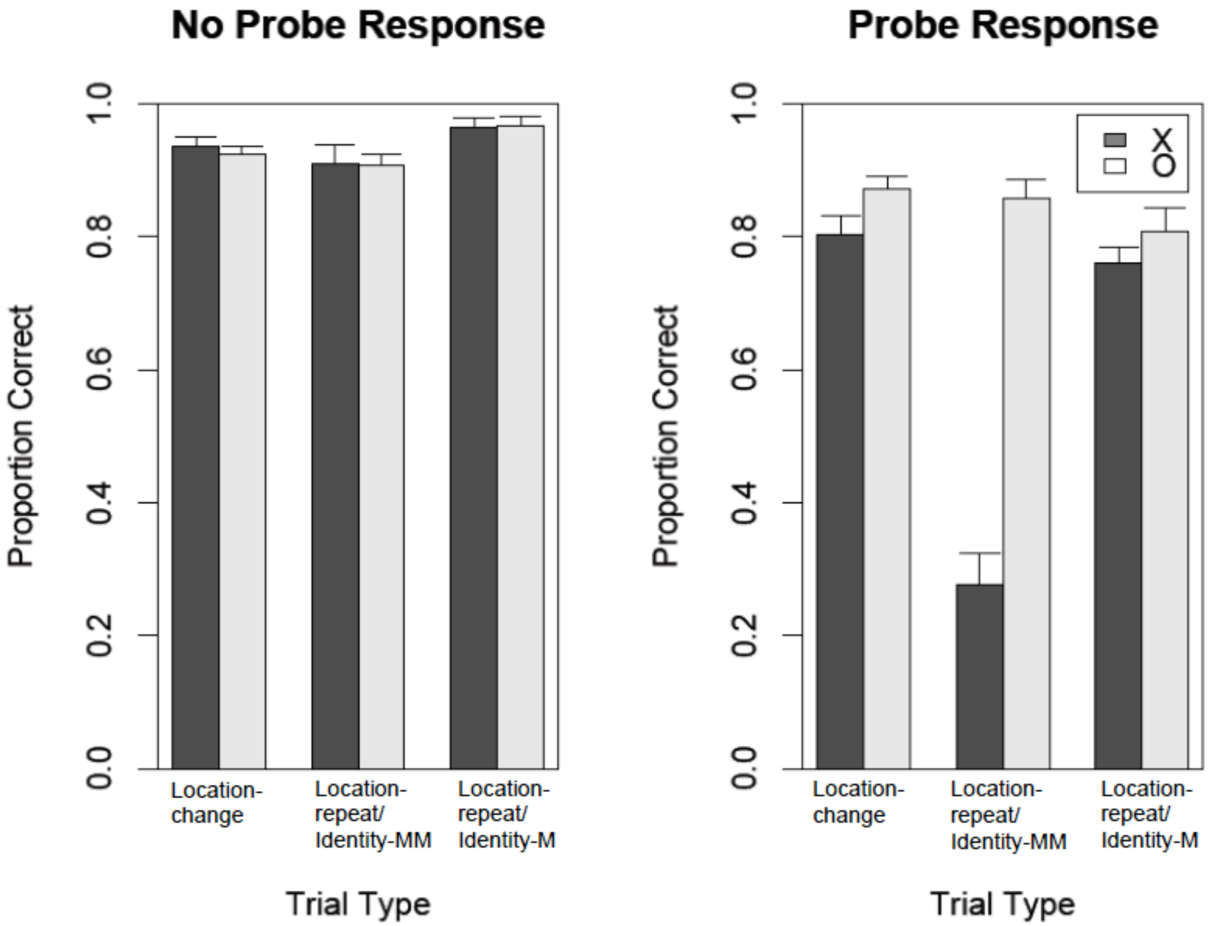

X
O
PRIME (157 ms)
“Remember location of both X & O”
ISI (500 ms)
O
X
PROBE (157 ms)
Respond/No Respond
ISI (700 ms or
until response)
1
2
X
3
4
TEST (until
response)
“Indicate location of cued letter”

Figure 5.


No Probe Response
Probe Response
Proportion Correct
0.0
0.2
0.4
0.6
0.8
1.0
■ X
□ O
Location-change
Location-repeat/Identity-MM
Location-repeat/Identity-M
Trial Type

CHAPTER 4: Visual Memory for Feature Bindings: The Disruptive Effects of Responding to New Perceptual Input.

Fiacconi, C.M., & Milliken, B. (submitted).

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PREFACE

While the focus of Chapter 3 was the relationship between 'contingency blindness' and the mnemonic consequences of binding mismatches, the focus of Chapter 4 was these mnemonic consequences themselves. Although itself informative in the context of understanding contingency awareness, the large mnemonic impairment associated with binding mismatches observed in Chapter 3 left open many questions with respect to the nature of the processes responsible for producing this effect. The experiments conducted in Chapter 4 were designed to better understand these processes by delineating the boundary conditions under which this impairment can be observed. The results from Chapter 4 suggested that merely attending to a mismatching target item that appeared in the same location as previous item is not sufficient to impair memory for this initial item, and that binding a response code to the subsequent target item is critical in observing this effect. Furthermore, this effect could not be attributed to biases at the time of encoding, as the removal of such biases did not eliminate the impairment. Finally, this effect was observed even when the target item was dissimilar from the previously encoded items. The results of Chapter 4 are discussed with reference to their implications for theories of visual memory.

Abstract

In the current study, we examined how short-term memory for location-identity feature bindings is influenced by subsequent cognitive and perceptual processing demands. Previous work has shown that memory performance for feature bindings can be disrupted by the presentation of subsequent visual information, particularly when this information is similar to that held in memory. The present study demonstrates that memory performance for feature bindings can be profoundly disrupted by also requiring a response to visual information presented subsequent to the visual memory array. Across five experiments, memory for a location-identity binding was substantially impaired following a localization response to a following item that matched the location but mismatched the identity of the memory target. The results point to an important role for action in the episodic integration processes that control short-term visual memory performance.

Introduction

A fundamental property of human cognition is the ability to represent visual information that is no longer present in the environment. Studies of visual memory typically present participants with an array of items and then require report of some or all of those items a short time later. Early research in this domain distinguished between an unlimited capacity iconic memory system and a limited-capacity visual working memory (VWM) system. Whereas the contents of iconic memory were thought to be short-lived and vulnerable to masking (Sperling, 1960; Averbach & Coriell, 1961), the contents of VWM were thought to be more durable and resistant to disruption from subsequent input (Phillips, 1974).

More recent research has shown that VWM performance can be impaired by new visual information presented subsequent to the presentation of a critical visual memory array (Wheeler & Treisman, 2002, Alvarez & Thompson, 2009; Sligte, Scholte, & Lamme, 2008, Landman, Spekriejse, & Lamme, 2003; Makovski, Sussman, & Jiang, 2008; Allen, Baddeley, & Hitch, 2006; Makovski, Watson, Koutstaal, & Jiang, 2010). In the present study, we focus on a unique property of VWM disruption that has not been studied systematically in prior research. Rather than measuring visual memory deficits produced by the presentation of subsequent visual information alone, we focus on visual memory deficits produced by subsequent visual information that is acted upon by the participant.

Although clearly relevant to the field of visual memory, the idea that responses to visual information involve the integration of prior episodes into ongoing experience is also relevant in the attention and performance domain. Note that many studies aimed primarily at attention processes require participants to respond selectively to targets on trials separated by short durations, and that integration of stimulus-response episodes from prior trials with current processing offers one potential explanation of inter-trial repetition effects (Kahneman, Treisman & Gibbs, 1992; Hommel, 1998; Park & Kanwisher, 1994; Neill, Valdes, Terry & Gorfein, 1992; Logan, 1988). Despite increasing interest in episodic integration processes in performance task contexts, there has been almost no research that combines the continuous responding requirements of attention and performance tasks with explicit requirements to remember. To our knowledge, the first experiment to address this issue directly was reported in a recently published study of ours (Fiacconi & Milliken, 2012; Experiment 3). The aim of that study was to examine why participants sometimes remain unaware of relatively strong inter-display contingencies in tasks that require participants to respond to the second of two displays presented in succession. The results from that study indicated that responding to the second of two displays, under some conditions, can result in profoundly poor memory for the contents of the first display, which in turn can explain poor awareness of inter-display contingencies.

Whereas the focus of our prior study was the contribution of an action-induced visual memory impairment to the learning of contingencies in a performance task, the focus of the present study was this visual memory impairment itself. Although our prior study pointed to an important contribution of action to this effect, the single experiment reported in that study left open a range of questions about the processing basis for the effect. Prior to describing our research objectives more specifically, we briefly review prior studies that have demonstrated deficits in VWM performance as a consequence of subsequent perceptual input, and then describe in more detail the action-induced visual memory effect we reported in our prior study.

Visual memory for feature bindings: Sensitivity to subsequent perceptual input

A procedure commonly used to study visual memory is the *change detection task*. In this task, participants are first presented with an array of items to memorize (usually colored squares). Following a short retention interval, a test display appears and participants are to indicate whether the test display is the same or different from the memory array. On some trials, the memory array and test displays are identical, while on other trials the test display contains a different element that was not presented in the memory array. Using this procedure, it has been estimated that the capacity of VWM is around 3-4 items (Luck & Vogel, 1997).

A great deal of research in this domain has centered on the question of whether VWM stores individual *features* or whether bound combinations of features known as *objects* can also be stored (Luck & Vogel, 1997; Wheeler & Treisman, 2002; Vogel, Woodman, & Luck, 2001; Delvenne & Bruyer, 2004; Xu, 2002; Saiki, 2003). Evidence for the view that VWM stores objects was reported in a seminal study by Luck and Vogel (1997). Participants were shown a memory array consisting of four bicolored squares that were made up of an inner and an outer square. Following a 900 ms retention interval, a test display was shown and participants had to determine whether the test display was identical to the memory array, or whether one part of one square had changed to a color not previously seen on that trial. The critical finding from this study was that memory performance when participants were told to remember the color of both parts of each square was identical to memory performance when participants were instructed to remember the color of only one part (inner or outer) of each square. This result suggests that VWM can store information in object-based units, and that therefore VWM is not limited to feature-based storage. Other researchers, however, have found this result difficult to replicate (Wheeler & Treisman, 2002; Delvenne & Bruyer, 2004).

Evidence for mnemonic binding across other feature dimensions has also been somewhat inconsistent (Wheeler & Triesman, 2002; Alvarez & Thompson, 2009). For example, Wheeler and Treisman (2002) conducted an experiment investigating color-location binding using the standard change detection task. Critically however, memory for color-location bindings was measured using memory and test arrays in which all the items were identical on same trials, whereas all colors and locations repeated but in a different configuration on different trials. It might be argued that this procedure is a better test of memory for bindings than that used by Luck and Vogel (1997) because it forces the participant to discriminate between feature re-combinations. In addition, participants were tested in either a *whole-display* test condition or a *single probe* test condition. In the whole display condition, the number of items appearing in the test display matched that of the memory array. In contrast, in the single probe condition, only a single item appeared in the test display. The key finding from this experiment was that reliable memory for feature bindings was observed in the single probe condition, but not in the whole display condition. One interpretation of this result is that maintaining color-location bindings in memory requires attention, and that in the whole display condition, attentional resources are needed during the test display to link together the new color and location information to create a bound representation (Treisman & Gelade, 1980; Wheeler & Treisman, 2002). The diversion of attentional resources away from maintaining the initial bindings and towards the creation of new bindings during the test display may compromise the representation of the feature bindings held in memory and subsequently produce poor memory performance. In the single probe condition, however, few attentional resources are required to perceive the new object at test, and therefore attention is not diverted away from maintaining the initial color-location bindings (but see Johnson, Hollingworth, & Luck, 2009 for evidence that casts doubt on this interpretation).

An alternative account, however, is that the onset of multiple feature re-combinations in the whole display test condition is treated as a perceptual update that disrupts or overwrites the memory representation of the initial memory array (Alvarez and Thompson, 2009; see Makovski, Sussman, & Jiang, 2008; Sligte, Scholte, & Lamme, 2008; Landman, Spekreijse, & Lamme, 2003 for similar ideas). Evidence in favor of this hypothesis comes from a study by Alvarez and Thompson (2009) who compared memory performance for color-location bindings in a change detection task with memory performance for the same information in a cued-recall task. In the cued-recall procedure, participants were shown a memory array and then given either a location cue or a color cue. The task was to provide the corresponding color to the location cue, or the corresponding location to the color cue. If feature re-combinations presented at test disrupt memory performance for bound objects, then memory for bindings as assessed by the change-detection task ought to be worse than memory performance for bindings when assessed by the cued-recall procedure. This was precisely the pattern of results obtained by Alvarez and Thompson (2009). It seems then that whether one can reliably measure object-based effects in visual memory depends on the specific measurement tool used (see Makovski, Watson, Koutstaal, & Jiang, 2010, for further discussion of this issue).

The idea that feature bindings stored in VWM are relatively fragile has also been proposed recently by Ueno and colleagues (Ueno, Allen, Baddeley, Hitch, & Saito, 2011; Ueno, Mate, Allen, Hitch, & Baddeley, 2011; Allen, Baddeley, & Hitch, 2006). Using the single probe method employed by Wheeler and Treisman (2002), Ueno and colleagues found that presenting participants with an irrelevant colored shape, or *visual suffix*, during the retention interval of a change detection task resulted in greater disruption to memory performance for color-shape feature bindings than for either feature alone. Notably, this decrement in memory for feature bindings was most evident when the suffix was comprised of features that could have potentially been part of the to-be-remembered set of items. The authors interpreted their results as reflecting the vulnerability of memory for feature bindings to overwriting from subsequent perceptual input.

Together, the results summarized above point to a growing consensus that visual memory performance can be disrupted by perceptual input presented subsequent to the memory array. In particular, visual memory for feature bindings seems especially vulnerable to such disruption. In the following section, we describe a recent study in which visual memory for feature bindings was disrupted profoundly by perceptual input presented subsequent to the memory array that required an action on the part of participants. As noted earlier in the introduction, this effect holds relevance both for the visual memory literature proper, but also for a vast attention and performance literature that uses tasks that require continuous trial-to-trial responding.

Visual memory for feature bindings: An action-induced disruption

Fiacconi and Milliken (2012, Experiment 3) presented participants with a memory array containing an X and an O in two of four demarcated locations for 157 ms (see Figure

1). Following a 500 ms inter-stimulus interval (ISI), an *intervening display* appeared. The intervening display consisted of another X and O in two of the four demarcated locations. Two groups of participants differed with respect to their instructions regarding this intervening display. The Response group was instructed to localize by key-press the target letter O in the intervening display, while the No Response group was instructed to attend and observe the intervening display without responding. Following the intervening display, participants were given a letter cue (either X or O) and were asked to indicate the location in which they thought the cued letter appeared in the memory array.

The key finding in this experiment was that memory performance was profoundly impaired when participants were asked to remember the location of the X in the memory array when it was subsequently replaced by a target O in the intervening display. Of crucial importance, this impairment occurred *only* in the Response group. That is, responding to the location of a letter that spatially overlapped a different letter resulted in very poor memory for the location of the overlapped letter. It is noteworthy that no such interference effect occurred when participants were required to remember an overlapped letter that matched a responded-to letter that subsequently appeared in the same location. Thus, the key effect hinged on spatial overlap between the target in the memory array and a letter in a following array, a mismatch in identity between those two letters, and a response to the second of those letters. One interpretation of this effect is that responding to the mismatching letter creates a new binding between location and identity that conflicts with the location-identity binding that has to be remembered. As such, we might refer to this effect as a *response-induced binding mismatch deficit.*

At the same time, although the contribution of responding to this effect appeared quite compelling, there were properties of the procedure used in that initial study that were holdovers from a related attention and performance domain (the spatial negative priming task; see Tipper, Brehaut & Driver, 1990; Milliken, Tipper, Houghton & Lupianez, 2000), and that left the results open to alternative interpretations. For example, the response-induced binding mismatch deficit.was found using a task in which the intervening display contained two probes, with a selective response required to one of those two probes. As noted earlier, presentation of multiple probe items could increase attentional demands at the time of the intervening display, which could in turn contribute to forgetting of feature bindings associated with the prior memory array. In Experiment 1 of the present study, we addressed this issue by examining whether a similar effect would occur with just a single probe item. In our prior study it was also the case that participants knew prior to onset of the memory array the target that they were to respond to in the intervening display. Consequently, attention may have been biased away from one of the memory array items, and indeed the key effect we reported involved a failure to remember precisely this item. In Experiments 3 and 4 of the present study, we asked whether a similar effect would occur without biased attention toward one of the two memory array items. Finally, in our prior study we manipulated whether participants responded to the intervening event between groups, and consequently could not determine whether attention to an intervening event item on its own (without a response) might be sufficient to produce the memory effect that we observed. We addressed this issue in both Experiments 2 and 5 of the present study using a go/no-go procedure. Across all five experiments, responding to the location of a target item in the intervening display substantially impaired memory performance for mismatching items that appeared in the same location in the memory array.

Experiment 1

The purpose of Experiment 1 was to assess whether a response-induced binding mismatch deficit would occur with a procedure similar to that used in our prior study (Fiacconi & Milliken, 2012), but with just a single probe item in the intervening display. We reasoned that for the Response group of the original study, the requirement to attend to one of two probes in the intervening display could deplete attentional resources and leave participants particularly vulnerable to forgetting of location-identity bindings from the memory array. To test this hypothesis, we removed the distracter letter X from the intervening display and asked participants to attend and localize a lone target letter O. If the requirement to attend selectively to a target item in the intervening display is critical, then the response-induced binding mismatch deficit should not be observed here.

Method

Participants. Participants were 24 McMaster University undergraduate students who participated in exchange for course credit. There were 17 females, and the mean age of the participants was 20.6 years. The 24 participants were randomly assigned to either the Response group or the No Response group. Each group consisted of 12 participants. All participants had normal or corrected-to-normal vision.

Apparatus and Stimuli. The experiment was carried out on a Pentium IBM compatible computer equipped with a NEC MultiSync colour monitor. Participants were seated approximately 40 cm from the monitor. Responses were made using a standard keyboard interfaced with the computer. Response times were measured using the routines published by Bovens and Brysbaert (1990).

The stimuli in the memory array appeared in two of four locations, marked by light grey boxes just above, below, left, or right of fixation. The boxes were positioned such that the horizontal visual angle between the centers of the left and right boxes was 5.0° and the vertical visual angle between the centers of the top and bottom boxes was 4.3°. Each box subtended a visual angle of 1.6° horizontally and 1.7° vertically. The letter ‘O’ appeared in the center of one of the boxes and the letter ‘X’ appeared inside another of the boxes in each memory array. Both letters were light grey and subtended 0.9° horizontally and 1.0° vertically. In the intervening display, only a single letter O appeared in one of the four marked locations. For the test display, the numbers 1 through 4 appeared in the four marked boxes along with a memory cue (letter X or O) appearing in the center of the display.

Procedure and Design. The trial sequence for Experiment 1 is depicted in Figure 2. Two groups of participants were included in this experiment: the Response group, and the No Response group. For the No Response group, the memory array appeared for 157 ms, and participants were instructed to remember the location of both the X and the O. Participants were told that at the end of each trial they would be asked to indicate the location of one of the two letters but were not told in advance which letter would be tested. Following an inter-stimulus interval (ISI) of 500 ms, the intervening display appeared for 157 ms and participants were instructed to pay attention but not to respond to this display. The test display then appeared 600 ms after the offset of the intervening display. In the test display, the four potential target locations were numbered 1-4 and a memory cue, either an X or an O, appeared in the center of the screen. Participants indicated where they thought the cued letter had appeared during the memory array by pressing keys 1-4. Memory for each of the two letters (X and O) was tested equally often across the experiment. Responses to the test display were not speeded, but participants were instructed to try to respond within three seconds. After response to the test display, the screen cleared and the next trial began. Each trial was self-paced and participants pressed the space bar to begin the next trial.

For the Response group, the procedure was much the same except that participants were instructed to localize and respond to the target letter O in the intervening display as quickly and accurately as possible. Participants made their responses to the intervening display using a keyboard where 'W' mapped onto the top location, 'S' mapped onto the bottom location, 'J' mapped onto the left location, and 'K' mapped onto the right location. A brief high-pitched tone was presented as feedback following incorrect localization responses. The test display appeared immediately after the response to the intervening display. Upon onset of the test display, participants in the Response group used the same keys ('W', 'S', 'J', 'K') to indicate their response to the memory test.

For both groups, the contents of the intervening display was varied such that the target letter O could appear in a location that was previously unoccupied in the memory array (Location-change), in a location that was previously occupied by the O in the memory array (Match), or in a location that was previously occupied by the X in the memory array (Mismatch). The proportions of trials for these three trial types were equal (.33) and each trial type was presented mixed together within 6 blocks of 24 trials each for a total of 144 trials. For Location-change trials, the subsequent memory cue that appeared in the test display necessarily always cued an item from the memory array that was not subsequently overlapped in the intervening display. However, for Mismatch trials and Match trials, the memory cue in the test display could cue either the item from the memory array that was subsequently overlapped (the Overlap condition), or the item from the memory array that was not subsequently overlapped (the Non-Overlap condition).

The combination of Location-change, Mismatch, and Match trials with the two possible memory cues (X/O) therefore resulted in a total of five different conditions: **a)** *Location-change* – target letter O in the intervening display appears in an unoccupied location from the memory array (data from the two different memory cues in this condition were collapsed to create a single Location-change condition) **b)** *Mismatch/Overlap* – target letter O in the intervening display appears in the location of a mismatching letter X from the memory array, and participants are cued in the test display to remember the location of the overlapped item **c)** *Mismatch/Non-Overlap* – target letter O in the intervening display appears in the location of a mismatching letter X from the memory array, and participants are cued in the test display to remember the location of the non-overlapped item **d)** *Match/Overlap* – target letter O in the intervening display appears in the location of a matching letter O from the memory array, and participants are cued in the test display to remember the location of the overlapped item **e)** *Match/Non-Overlap* – target letter O in the intervening display appears in the location of a matching letter O from the memory array, and participants are cued in the test display to remember the location of the non-overlapped item. The exact number of each of these different conditions varied slightly across blocks due to the pseudo-random selection of the memory cue (X/O) on each trial. Note that the last four conditions constitute a factorial combination of two variables, which we label Binding (Mismatch/Match) and Overlap (Overlap/Non-Overlap).

Participants in both groups were given a one-minute rest break after every 48 trials. Prior to the experimental session, both groups of participants performed a practice session consisting of 24 trials.

Results

The critical dependent variable in this experiment was the proportion of trials on which participants were correct in indicating where the cued letter in the test display appeared in the memory array. For the Response group, trials on which participants made an incorrect localization response to the target letter in the intervening display were excluded from our analysis of memory accuracy. The mean localization error rates for each condition can be found in Table 1. The mean proportion of correct responses to the test display for each condition can be found in Figure 3**.** All post-hoc comparisons were performed using the Fisher's Least Significant Difference (LSD) procedure to protect against Type I error inflation unless otherwise stated.

Our analysis strategy for Experiment 1 was as follows. We first conducted a mixed factor analysis of variance (ANOVA) that treated Group (Response/No Response) as a between-subjects factor, and Binding (Mismatch/Match) and Overlap (Overlap/Non-Overlap) as within-subjects factors. This analysis allowed us to examine the effect on memory performance of responding to an item that mismatches/matches one of the items from the memory array as a function of whether the cued item in the test display was overlapped or not. Following this analysis, for each group we compared memory accuracy on Location-change trials with memory accuracy on Mismatch/Non-Overlap and Match/Non-Overlap trials. This analysis examined whether memory performance for a non-overlapped item was poorer when participants were exposed to a mismatching/matching item compared to when no such mismatching/matching item was present.

The mean proportion of correct responses to the test display for each condition were submitted to the above described ANOVA. This analysis revealed a significant main effect of Binding, $F(1, 22) = 14.0$, $p = .002$, $\eta_p^2 = .39$, indicating that memory accuracy was poorer on mismatch trials (.79) than on match trials (.90). Critically, however, there was a significant three-way interaction between Group, Binding, and Overlap, $F(1, 44) = 8.47$, $p = .008$, $\eta_p^2 = .27$. To examine this interaction further, the effects of Group and Overlap were analyzed separately for Mismatch and Match trials.

For Mismatch trials, a 2 (Response/No Response) x 2 (Overlap /Non-Overlap) mixed factorial ANOVA revealed a significant main effect of Group, $F(1, 22) = 12.1$, $p =.002$, $\eta_p^2 = .35$, with poorer memory accuracy for the Response group (.66) than for the No Response group (.91). There was also a significant interaction between Group and Overlap, $F(1, 22) = 15.9$, $p <.001$, $\eta_p^2 = .42$. For the Response group, memory accuracy was poorer for Overlap trials than for Non-Overlap trials, $t(11) = 5.06$, $p <.001$, $d = 1.18$ (see the mismatch trials in the left panel of Figure 3). In other words, memory performance was particularly poor when an X from the memory array was overlapped by an O that was responded to in the intervening display – a replication of the response-induced binding mismatch deficit reported by Fiacconi and Milliken (2012). For the No Response group, memory accuracy for Overlap trials did not differ from Non-Overlap trials ($p =.19$).

For Match trials, a 2 (Response/No Response) x 2 (Overlap/Non-Overlap) mixed factorial ANOVA revealed a significant main effect of Group, $F(1, 22) = 4.60$, $p = .043$, η_p^2

= .18 with poorer memory accuracy for the Response group (.84) than for the No Response group (.96). No other main effects or interactions reached significance.

For the Response group, memory accuracy for Location-change trials was no different than that for Mismatch/Non-Overlap trials (*p* = .36), nor was it different than that for Match/Non-Overlap trials (*p* = .09). These results demonstrate that performance for memory array items that were not overlapped did not differ across conditions for this group.

For the No Response group, memory accuracy for Mismatch/Non-Overlap trials was poorer than that for Location-change trials, $t(11) = 3.11$, $p = .010$, $d = .90$. There was no difference in memory accuracy for Location-change trials relative to Match/Non-Overlap trials (*p* = .77). These results indicate that memory performance for memory array items that were not overlapped was slightly, but significantly, poorer for Mismatch trials than for Location-change trials (see the Location-change and Non-Overlap conditions in the right panel of Figure 3).

Discussion

The primary purpose of Experiment 1 was to replicate and extend the key response-induced binding mismatch deficit reported by Fiacconi and Milliken (2012). Specifically, we asked whether the presence of this effect was contingent upon selective attention demands during the intervening display. A large response-induced binding mismatch deficit was observed in the absence of selective attention demands during the intervening display, a finding that replicates the critical result from Fiacconi and Milliken (2012).

It remains an open question as to why responding to a location-identity binding mismatch produces such a profound memory deficit. The process of directing a response toward the target letter O presumably requires attention in and of itself, and it is unclear whether it is *attending* or *responding per se* to the target letter that is critical in producing this deficit. This issue was the focus of Experiment 2.

Experiment 2

The purpose of Experiment 2 was to disentangle the contribution of response-related attentional allocation from responding per se to the production of the response-induced binding mismatch deficit measured here in Experiment 1 and by Fiacconi and Milliken (2012). To separate the contribution of these two factors, we used a Go/No-go task. Each trial was defined as a Go or No-go trial based on the color of the target letter O in the intervening display. A trial was defined as a Go trial if the target letter O appeared in green. Conversely, a trial was defined as a No-go trial if the target letter O appeared in red. On Go trials, participants were required to respond by localizing the target letter O. On No-go trials, participants were required to withhold their response to the target letter O. The intervening display in this experiment always consisted of the target letter O as well as a distractor letter X. One of these two letters was red and the other was green, and participants were to respond to the letter presented in green. Inclusion of the distractor letter X in the intervening display ensured that participants had to attend to identity in addition to color information when deciding whether each trial was a Go trial or a No-go trial. The key property of this task is that for No-go trials, participants had to attend to the target letter O in the intervening display in order to decide whether to respond. Therefore, if *attending* to the target letter O in the intervening display is sufficient to produce the response-induced binding mismatch deficit, then we should observe this effect on both Go and No-go trials. In contrast, if *responding* to the target letter O in the intervening display is critical to producing this effect, then we should observe this effect only on Go trials.

Method

Participants. Participants were 21 McMaster University undergraduate students who participated in exchange for course credit. There were 17 females, and the mean age of the participants was 18.7 years. All participants had normal or corrected-to-normal vision.

Apparatus and Stimuli. These were the same as in Experiment 1 with the following exception: the intervening display in this experiment consisted of an 'X' and an 'O' appearing in two of the four demarcated locations. The 'X' and the 'O' always appeared in one of two possible colors – red and green. The two letters always appeared in opposite colors. The distractor letter X in the intervening display always appeared in a location that was previously unoccupied in the memory array.

Procedure and Design. The basic procedure for Experiment 2 was similar to that of Experiment 1. Trials were self-paced and participants pressed the space bar to begin each trial. Similar to Experiment 1, Experiment 2 contained Location-change trials in addition to the conditions that resulted from the factorial combination of Binding (Mismatch/Match) and Overlap (Overlap/Non-Overlap). Each memory cue (X/O) was presented equally often throughout the experiment. For each condition, half of the trials were Go trials, and the other half were No-go trials. The response status of each trial was given by the color of the letter O in the intervening display. On Go trials, the letter O appeared in green and participants were instructed to respond to the location of the O using the same button mapping as in Experiment 1. On No-go trials, the letter O appeared in red and participants were instructed to withhold their response to the location of the O. On Go-trials, the test display appeared immediately following the participants' response to the intervening display. On No-go trials, the test display was presented 600 ms after the offset of the intervening display. Participants responded to the test display using the same mapping as in Experiment 1 and their responses were not speeded. All conditions were presented mixed together in 30 blocks of 12 trials each for a total of 360 trials. Prior to the experimental session, participants performed a practice session consisting of 24 trials. During the experimental session, participants were given a one-minute rest break after every 48 trials.

Results

As in Experiment 1, trials on which participants responded incorrectly to the intervening display were excluded from the analyses of memory performance. These incorrect responses included responses on a No-go trial, as well incorrect localization responses on a Go trial. The mean localization error rates for each condition can be found in Table 1. The mean proportion of correct responses to the test display for each condition can be found in Figure 4**.**

Our analysis strategy in Experiment 2 was similar to that in Experiment 1. We first conducted a repeated measures ANOVA that treated Response Status (Go/No-go), Binding (Mismatch/Match), and Overlap (Overlap/Non-Overlap) as within-subject factors. Following this analysis, for both Go and No-go trials we compared memory accuracy on Location-change trials with memory accuracy on Mismatch/Non-Overlap trials and Match/Non-Overlap trials.

The mean proportion of correct responses to the test display for each condition were submitted to the above described ANOVA. This analysis revealed a significant main effect of Binding, $F(1, 20) = 22.4$, $p < .001$, $\eta_p^2 = .53$, indicating that memory accuracy was poorer on Mismatch trials (.78) relative to Match trials (.85). Critically, however, there was a significant three-way interaction between Response Status, Binding, and Overlap, $F(1, 20) = 12.9$, $p = .002$, $\eta_p^2 = .39$. To examine this interaction further, the effects of Response Status and Overlap were analyzed separately for Mismatch and Match trials.

For Mismatch trials, a 2 (Go/No-go) x 2 (Overlap/Non-Overlap) repeated-measures factorial ANOVA revealed a significant main effect of Response Status, $F(1, 20) = 19.5$, $p < .001$, with poorer memory accuracy on Go trials (.72) relative to No-go trials (.84) There was also a significant interaction between Response Status and Overlap, $F(1, 20) = 32.5$, $p < .001$, $\eta_p^2 = .61$**.** Subsequent comparisons revealed that memory accuracy on Go trials was poorer for Overlap trials relative to Non-Overlap trials, $t(20) = 7.95$, $p < .001$, $d = 1.74$ (see the mismatch trials in the left panel of Figure 4). Once again, memory performance was particularly poor when an X from the memory array was overlapped by an O that was responded to in the intervening display. This result constitutes a nice replication of the response-induced binding mismatch deficit reported in Experiment 1 (see also Fiacconi and Milliken, 2012, Experiment 3). For No-go trials, there was no difference in memory accuracy between Overlap trials and Non-Overlap trials ($p = .14$).

For Match trials, a 2 (Go/No-go) x 2 (Overlap/Non-Overlap) repeated-measures factorial ANOVA revealed a significant main effect of Response Status, $F(1, 20) = 20.7$, $p < .001$, $\eta_p^2 = .51$, with poorer memory accuracy on Go trials (.80) relative to No-go trials (.89). There was also a significant interaction between Response Status and Overlap, $F(1,$

20) = 4.85, $p = .040$, $\eta_p^2 = .20$. Subsequent comparisons revealed that memory accuracy on Go trials was poorer for the Overlap trials relative to the Non-Overlap trials, $t(20) = 2.24$, $p = .037$, $d = .49$. (see the match trials in the left panel of Figure 4). In this case, memory performance was poor when an O from the memory array was overlapped by an O that was responded to in the intervening display, a result not observed in prior experiments (see Experiment 1; Fiacconi and Milliken, 2012, Experiment 3). For No-go trials, there was no difference in memory accuracy between Overlap trials and Non-Overlap trials ($p = .90$).

On Go trials, memory accuracy for Location-change trials was no different than that for Mismatch/Non-Overlap trials ($p = .68$), although it was marginally better than that for Match/Non-Overlap trials ($p = .07$).

On No-go trials, memory accuracy for Location-change trials was was marginally better than that for Mismatch/Non-Overlap trials ($p = .06$), but was no different than that for Match/Non-Overlap trials ($p = .22$).

Discussion

The primary aim of Experiment 2 was to better understand why the response-induced binding mismatch deficit observed by Fiacconi and Milliken (2012) and in Experiment 1 of the current paper was observed in the Response group. We asked whether responding *per se* to a mismatching target item in the intervening display was the critical factor in producing this mnemonic deficit, or whether simply attending to mismatching items was sufficient to produce this effect. The results from Experiment 2 provide unambiguous support for the hypothesis that responding plays a critical role in this effect. That is, large response-induced binding mismatch deficits were not observed when participants merely attended to the item that overlapped and mismatched the memory target. Rather, execution of a localization response to this item was critical for observing this effect.

One intriguing aspect of the results of Experiment 2 was that for Go trials, there was a modest decrement in memory performance for Match/Overlap trials relative to Match/Non-Overlap trials. Recall that this contrast compares memory performance for an item that was subsequently overlapped by an identical item (a location-identity binding match), with memory performance for an item that was not subsequently overlapped. This result suggests that under some circumstances, responding to an item that shares an identity with an item that previously appeared in the same location can actually impair memory performance for the initial item. At first blush, this result seems inconsistent with the idea that responding to a *mismatching* item that overlaps the memory target is the key factor that produces large memory decrements. However, it should be noted that items in the intervening display in Experiment 2 always *mismatched* the prior memory array in terms of color. Therefore, a location-identity binding match on these trials might not be treated as such given the salient difference in color between the memory array and the intervening display. This color difference could help explain why memory performance in this condition is moderately impaired.

To this point, the results appear consistent with the view that responding to an item that overlaps and mismatches a memory array item can interfere with or ‘overwrite’ the representation of the memory array item. However, in both experiments reported thus far, participants always knew in advance the identity of the target in the intervening display (the letter O). We wondered whether this property of the procedure might bias encoding of the items in the memory array. That is, keeping the letter O in mind for the purpose of responding to this item in the intervening display might lead participants to attend and encode this item preferentially in the memory array. This idea is consistent with findings that support a close relationship between the focus of attention and working memory (Woodman & Luck, 2007; Awh & Jonides, 2001; Awh, Vogel, & Oh, 2006). All told, if this were the case, then the large response-induced binding mismatch deficits reported in Experiments 1 and 2 could be a consequence of poor initial encoding of a location-identity binding for the unattended X in the memory array, together with the interfering effects of responding to a mismatching O at that location in the intervening display. We addressed this issue in Experiment 3.

Experiment 3

The purpose of Experiment 3 was to determine whether the response-induced binding mismatch deficit observed in prior experiments would be observed with a procedure that rules out the possibility of biased encoding of the memory array items. To address this issue, the identity of the target letter in the intervening display varied randomly from trial to trial. This procedure ensured that participants could not hold in mind the target letter while encoding the memory array, and thus their attention would not be biased systematically toward one memory array item versus the other. If this biased encoding process was instrumental in producing the response-induced binding mismatch deficit, then we ought not to observe this effect in Experiment 3. In contrast, if responding to an item that mismatches the memory target were sufficient to produce such deficits, then we should observe this effect again in Experiment 3.

Method

Participants. Participants were 24 McMaster University undergraduate students who participated in exchange for course credit. There were 20 females, and the mean age of the participants was 18.6 years. The 24 participants were randomly assigned to either the Response group or the No Response group. Each group consisted of 12 participants. All participants had normal or corrected-to-normal vision.

Apparatus and Stimuli. These were the same as in Experiment 1 with the following exception: the intervening display in Experiment 3 consisted of a single 'X' or 'O' appearing in one of the four demarcated locations.

Procedure and Design. The basic procedure for Experiment 3 was very similar to that of Experiment 1. The major difference between Experiment 3 and Experiment 1 was that for Experiment 3, the identity of the target letter in the intervening display varied randomly from trial to trial. Participants in the Response group were instructed to respond to the location of the target letter regardless of its identity. Note that because the identity of the target letter varied randomly from trial to trial, when the target letter appeared in a previously occupied location, it could match or mismatch the letter that previously appeared in that location. Therefore, trials on which there was a binding mismatch could consist of an O in the intervening display appearing where an X had appeared in the memory array, or an X in the intervening display appearing where an O had appeared in the memory array (Mismatch). Correspondingly, trials on which there was a binding match could consist of an O in the intervening display appearing where an O had appeared in the memory array, or an X in the intervening display appearing where an X had appeared in the memory array (Match). The experimental session consisted of 8 blocks of 24 trials each for a total of 192 trials.

Results

As in prior experiments, trials on which participants responded incorrectly to the intervening display were excluded from the memory performance analyses. The mean localization error rates for each condition can be found in Table 1. The mean proportion of correct responses to the test display for each condition can be found in Figure 5**.**

Our analysis strategy for Experiment 3 was the same as that for Experiment 1. The mean proportion of correct responses to the test display for each condition were submitted to a mixed factor ANOVA that treated Group (Response/No Response) as a between-subjects factor, and Binding (Mismatch/Match), and Overlap (Overlap/Non-Overlap) as within-subject factors. This analysis revealed a significant main effect of Binding, $F(1, 22) = 20.2$, $p <.001$, $\eta_p^2 = .48$, with poorer memory accuracy on Mismatch trials (.87) than on Match trials (.93). There was also a significant interaction between these variables, $F(1, 22) = 6.8$, $p =.016$, $\eta_p^2 = .24$. To examine this interaction further, the effects of Group and Overlap were analyzed separately for Mismatch and Match trials.

For Mismatch trials, a 2 (Response/No Response) x 2 (Overlap/Non-Overlap) repeated-measures factorial ANOVA revealed a significant main effect of Group, $F(1, 22) = 15.6$, $p <.001$, $\eta_p^2 = .42$, with poorer memory accuracy for the Response group (.79) than for the No Response group (.94). There was also a significant interaction between Group and Overlap, $F(1, 22) = 18.2$, $p <.001$, $\eta_p^2 = .45$. Subsequent comparisons revealed that for the Response group, memory accuracy was poorer for Overlap trials than for Non-Overlap trials, $t(11) = 6.21$, $p <.001$, $d = 1.79$ (see the mismatch trials in the left panel of Figure 5). This result shows that memory performance was particularly poor for memory array items that were overlapped by a mismatching letter that was responded to in the intervening display. In this case, this response-induced binding mismatch deficit occurred in the absence of the potential for biased encoding of one of the two memory array items. For the No Response group, there was no difference in memory accuracy between Overlap trials and Non-Overlap trials (p =.69).

For Match trials, a 2 (Response/No Response) x 2 (Overlap/Non-Overlap) repeated-measures factorial ANOVA revealed a significant main effect of Group, $F(1, 22) = 5.67$, p =.026, $\eta_p^2 = .20$, with poorer memory accuracy for the Response group (.90) than for the No Response group (.97). No other main effects or interactions reached significance.

For the Response group, memory accuracy for Mismatch/Non-Overlap trials was poorer than that for Location-change trials, $t(11) = 3.54$, $p = .005$, $d = 1.02$. There was no difference in memory accuracy for Location-change trials relative to Match/Non-Overlap trials ($p = .99$). These results indicate that memory performance for memory array items that were not overlapped was slightly, but significantly, poorer for Mismatch trials than for Location-change trials (see the Location-change and Non-overlap conditions in the right panel of Figure 5).

For the No Response group, memory accuracy for Location-change trials was no different than that for Mismatch/Non-Overlap trials ($p = .60$), nor did it differ from that for Match/Non-Overlap trials ($p = .58$). These results demonstrate that memory performance for memory array items that were not overlapped did not differ across conditions for this group.

Discussion

The goal of Experiment 3 was to measure the response-induced binding mismatch effect in an experiment that rules out the contribution of top-down encoding biases for one memory array item over the other. These top-down biases were removed by randomly selecting the identity of the target letter in the intervening display on a trial-by-trial basis. Despite not knowing in advance of each trial the identity of the target letter in the intervening display, participants in the Response group produced poorer memory accuracy for items that were subsequently superimposed by a mismatching item that required a response. Thus, Experiment 3 demonstrates that the response-induced binding mismatch deficit can occur in the absence of memory array encoding biases.

Experiment 4

In all of the experiments reported to this point, the identities of the items appearing in the intervening display were the same as those in the memory array. This repetition of item identity between the two displays might serve as a particularly potent source of memory disruption (Ueno et al., 2011a,b). In Experiment 4, we examined whether the response-induced binding mismatch deficit would occur when redundancy in item identity between the memory array and intervening display is absent.

Method

Participants. Participants were 24 McMaster University undergraduate students who participated in exchange for course credit. There were 17 females, and the mean age of the participants was 20.1 years. The 24 participants were randomly assigned to either the Response group or the No Response group. Each group consisted of 12 participants. All participants had normal or corrected-to-normal vision.

Apparatus and Stimuli. These were the same as in Experiment 1 with the following exception: the intervening display in Experiment 4 consisted of a J and an S appearing in two of the four demarcated locations.

Procedure and Design. The basic procedure of Experiment 4 was very similar to that of Experiment 1. The major difference between Experiment 4 and Experiment 1 was that for Experiment 4, the use of two new non-redundant letters in the intervening display implied that there were no location-identity binding match trials. The exclusion of Match trials in Experiment 4 resulted in this experiment containing only three different conditions per group: **a)** *Location-change* – target letter J in the intervening display appears in an unoccupied location from the memory array (we collapsed across the two different memory cues to create a single Location-change condition) **b)** *Mismatch/Overlap* – target letter J in the intervening display appears in the location of a mismatching letter from the memory array, and participants are cued in the test display to remember the location of the overlapped item **c)** *Mismatch/Non-Overlap* – target letter J in the intervening display appears in the location of a mismatching letter from the memory array, and participants are cued in the test display to remember the location of the non-overlapped item. Each block within the experimental session consisted of 24 trials and participants in each group completed 6 blocks for a total of 144 trials.

Results

As in prior experiments, trials on which participants responded incorrectly to the intervening display were excluded from the memory performance analyses. The mean localization error rates for each condition can be found in Table 1. The mean proportion of correct responses to the test display for each condition can be found in Figure 6.

Our analysis strategy for Experiment 4 was similar to that for Experiment 1. The only difference was that for the current experiment, there were no Match trials, and therefore our initial ANOVA treated Group (Response/No Response) as a between-subjects factor, and Overlap (Overlap/Non-Overlap) as a within-subject factor. Following this analysis, for each group we compared memory accuracy on Location-change trials with memory accuracy on Mismatch/Non-Overlap trials.

The mean proportion of correct responses to the test display for each condition were submitted to the above described ANOVA. This analysis revealed a significant main effect of Group, $F(1, 22) = 52.5$, $p <.001$, $\eta_p^2 = .71$, indicating that memory performance was poorer for the Response group (.65) than for the No Response group (.95). There was also a significant interaction between Group and Overlap, $F(1, 22) = 13.8$, $p =.001$, $\eta_p^2 = .39$. Subsequent comparisons revealed that for the Response group, memory accuracy for Overlap trials was poorer than for Non-Overlap trials, $t(11) = 4.67$, $p <.001$, $d = 1.35$ (see the mismatch trials in the left panel of Figure 6). This result demonstrates that the response-induced binding mismatch deficit occurs even in a context in which the memory array items are consistently different than the intervening display items. For the No Response group, memory accuracy for Overlap trials was not significantly different than that for Non-Overlap trials, although this difference did approach significance ($p =.053$).

For the Response group, memory accuracy for Location-change trials was no different than that for Mismatch/Non-Overlap trials ($p = .75$). For the No Response group, memory accuracy for Location-change trials was also no different than that for Mismatch/Non-Overlap trials (*p* = .22).

Discussion

Experiment 4 examined whether the response-induced binding mismatch deficit reported in Experiments 1-3 could be measured in the absence of redundancy in item identity between the memory array and intervening display. Indeed, we were able to measure this effect for the Response group suggesting that such deficits can occur when the identities of the intervening items are distinct from those held in memory. This finding is interesting in light of the results reported by Ueno and colleagues (Ueno et al., 2011a,b). Specifically, those authors consistently found a decrement in memory performance for feature bindings when participants were exposed in the retention interval to a visual suffix that shared features in common with items from the experiment-wide item set, relative to when the visual suffix did not share these common features. The results of Experiment 4 demonstrate that even in situations where the items in the intervening display are distinct from those in the memory array, memory performance for location-identity feature bindings can be vulnerable to disruption. Importantly, this disruption occurred when participants were required to respond to a target item in the intervening display, and when they were cued to remember a different item that appeared in the same location in the memory array.

Experiment 5

In Experiment 5, we extended the procedure of Experiment 4 to a Go/No-go task with the intent of providing converging evidence for the idea that binding mismatch deficits depend on the execution of a response toward a mismatching item rather than simply attending to such items.

Method

Participants. Participants were 11 McMaster University undergraduate students who participated in exchange for course credit. There were six females, and the mean age of the participants was 18.5 years. All participants had normal or corrected-to-normal vision.

Apparatus and Stimuli. These were the same as in Experiment 4 with the following exception: the 'J' and the 'S' always appeared in one of two possible colors – red and green. The two letters always appeared in opposite colors.

Procedure and Design. The basic procedure for Experiment 5 was similar to that of Experiment 2. The major difference between Experiment 5 and Experiment 2 was that the intervening display in this experiment contained the letters 'J' and 'S'. As a result, there were no location-identity binding matches in this experiment. Thus, Experiment 5 contained the same three conditions as Experiment 4. For each trial type, half of the trials were Go trials, and the other half were No-go trials. The response status of each trial was given by the color of the letter J in the intervening display. On Go trials, the letter J appeared in green and participants were instructed to respond to the location of the J using the same button mapping as in Experiment 1. On No-go trials, the letter J appeared in red and participants were instructed to withhold their response to the location of the J. All conditions were presented mixed together in 30 blocks of 12 trials each for a total of 360 trials.

Results

As in prior experiments, trials on which participants responded incorrectly to the intervening display were excluded from the memory performance analyses. These incorrect trials included those on which participants made a response on a No-go trial, as well trials on which participants made an incorrect localization response on a Go trial. The mean localization error rates for each condition can be found in Table 1. The mean proportion of correct responses to the test display for each condition can be found in Figure 7.

Our analysis strategy for Experiment 5 was similar to that for Experiment 2. The only difference was that for the current experiment, there were no Match trials, and therefore our initial ANOVA treated Response Status (Go/No-go) and Overlap (Overlap/Non-Overlap) as within-subject factors. Following this analysis, for Go and No-go trials, we compared memory accuracy on Location-change trials with memory accuracy on Mismatch/Non-Overlap trials.

The mean proportion of correct responses to the test display for each condition were submitted to a repeated measures factorial ANOVA that treated Response Status (Go/No-go), and Overlap (Overlap/Non-Overlap) as within-subjects factors. This analysis revealed a significant main effect of Response Status, $F(1, 10) = 19.8$, $p =.001$, $\eta_p^2 = .67$, indicating that memory performance was poorer for Go trials (.80) than for No-go trials (.91). The interaction between Response Status and Overlap approached significance, $F(1, 10) = 3.5$, $p =.09$, $\eta_p^2 = .26$. Subsequent planned comparisons revealed that for Go trials, memory accuracy was poorer for Overlap trials than for Non-Overlap trials, $t(10) = 2.60$, $p = .026$, $d = .78$. For No-go trials, the difference in memory accuracy between the Overlap and the Non-Overlap conditions approached significance ($p = .09$).

On Go trials, memory accuracy for Location-change trials was marginally better than that for Mismatch/Non-Overlap trials (*p* = .07). On No-go trials, memory accuracy for Location-change trials was no different than that for Mismatch/Non-Overlap trials (*p* = .31).

Discussion

Experiment 5 extended the results of Experiment 4 by demonstrating again the importance of responding to the binding mismatch deficit. Memory performance was worse for the Overlap than for the Non-Overlap condition for the Go trials but not for the No-go trials. As was the case for Experiment 4, this result is also noteworthy in that it demonstrates the response-induced binding mismatch deficit in a context in which the intervening display items are always different from the memory array items.

General Discussion

The focus of the present study was to examine the impact of responding to subsequent perceptual input on the online maintenance of visual information in memory. Indeed, little research to date has addressed how visual memory is influenced by the planning and execution of subsequent action. This empirical issue is central to an understanding of the role of visual memory in everyday contexts, as we are often required to store visual information temporarily while simultaneously interacting with the world around us. Successful interaction with our environment requires efficient coordination between information held in mind, and ongoing perception/action. The role of planning and execution of actions on visual memory also has important implications for the a vast literature that focuses on attention and performance issues. In particular, if actions directed toward visual stimuli can disrupt memory for items stored just a short time before, then those actions also hold the potential to limit explicit knowledge of statistical regularities in that performance domain (Fiacconi & Milliken, 2012). Given that explicit knowledge of statistical regularities can have profound effects on many tasks (Cheesman & Merikle, 1986; Eimer & Schlaghecken, 2002; Vaquero, Fiacconi, & Milliken, 2010), it seems clear that an understanding of the role of action on visual memory performance has important implications for the attention and performance domain.

The experiments reported in this paper represent a step toward understanding the role of subsequent action on visual memory performance. In Experiment 1, we asked whether the response-induced binding mismatch deficit reported by Fiacconi and Milliken (2012) would be observed in a context in which there was no selective attention requirement for the intervening display. The results indeed revealed particularly poor memory performance for the location of the letter X in the memory array when that letter was subsequently overlapped by the letter O and a response was made to that letter O. Experiment 2 examined whether this effect is related to the response itself or to the attention directed to a target prior to response. The results revealed that the response-induced mismatch binding deficit occurred for Go trials but not for No-go trials, implying that mere attention to the mismatching letter that subsequently overlaps the memory target is insufficient to produce the effect. Experiment 3 examined whether the effects reported in Experiments 1 and 2 (and also in Fiacconi & Milliken, 2012) owed to the fact that participants had a consistent intervening display target in mind (i.e., localize the O) at the time of onset of the memory array. In particular, if participants were always prepared to localize an O in the intervening display, this preparation may have biased attention away from the X in the memory array, leaving it vulnerable to interference from the mismatching O that followed. However, the results of

Experiment 3 revealed a response-induced binding mismatch deficit under conditions in which participants were unaware of the identity of the target in the intervening display until its onset, suggesting that biased encoding against the mismatched and superimposed item is not necessary to observe the effect. Finally, Experiments 4 and 5 examined the role of item similarity between the memory array and the intervening display by using different pairs of letters for the two displays. In both Experiments 4 and 5, there was a decrement in memory performance for items that were subsequently superimposed by a mismatching item that was responded to. Together, the results are consistent with the view that responding to a target can lead to location-identity binding processes that impair memory for a prior event that involved the same location bound to a different identity.

Two aspects of the results are particularly noteworthy. First, although memory performance in general was poorer when participants responded to the intervening display, the requirement to respond disproportionately impaired memory performance when a mismatching letter that was responded to subsequently overlapped the item being tested. The specificity of this memory impairment is quite striking – in Experiment 1, the requirement to execute a localization response to a mismatching letter in the intervening display increased the Overlap effect from .04 to .31. Second, large response-induced binding mismatch deficits were observed even when participants needed only to remember the location-identity binding of *two* items. According to many accounts of VWM, two bound objects are well within the capacity limits of this system (Luck & Vogel, 1997; Vogel, Woodman, & Luck, 2001). The fact that such large memory effects occurred in a task that required memory for just two objects speaks to the potency of responding to subsequent input as a source of mnemonic impairment.

It should be noted that decrements in memory performance for feature bindings have been demonstrated previously in studies in which a memory array is followed by presentation of new perceptual input (Wheeler & Treisman, 2002; Alvarez & Thompson, 2009; Ueno et al., 2011a,b). Perhaps the most similar of these prior studies are those reported recently by Ueno et al. 2011a,b). Ueno et al. (2011b) presented color-shape feature combinations in a memory array followed by an irrelevant visual suffix that sometimes shared features with items from the possible set of to-be-remembered items. Using a cued-recall procedure similar to that employed here, the results from their study revealed a larger memory decrement for color-shape feature bindings when the suffix shared features with the to-be-remembered set of items. In our experiments, we added response information to the 'suffix' that followed the memory array, and found that this added response information strongly disrupted memory performance. Further, given the important role of similarity between the features of the visual suffix and the set of items to be remembered in the Ueno et al. (2011a, b) studies, one might have expected not to see memory disrupted in Experiments 4 and 5 of the present paper, in which the featural similarity between the intervening display and the memory array was removed. Yet, the response-induced binding mismatch deficit (.23) was numerically *larger* in Experiment 4 than in Experiment 3 (.14). Future work will be necessary to identify more precisely how the featural similarity of subsequent input impacts memory for feature bindings.

What Mechanism is Responsible for Producing the Response-Induced Binding Mismatch Deficit?

What remains to be determined is the precise mechanism that causes response-induced binding mismatch deficit. One candidate mechanism is "overwriting" (Alvarez &

Thompson, 2009; Ueno et al., 2011a,b; Allen et al., 2006). By this view, memory impairments may be a consequence of new incoming perceptual input "overwriting" the representation of the target feature binding from the memory array. A particular variant of the overwriting hypothesis was forwarded by Ueno et al. (2011a,b). They proposed that overwriting of representations in VWM is mediated by a top-down control mechanism that "protects" stored representations by filtering out or discarding new input prior to entry to VWM. This filtering process can fail when subsequent perceptual input is similar to the information stored in VWM. In this way, the proposed mechanism can account for the fact that memory for feature bindings suffers most when the feature overlap between the stored representations and the new perceptual input is high (Ueno et al., 2001a,b).

In line with the Ueno et al. (2011a, b) overwriting hypothesis, it could be argued that responded-to items from the intervening display in the present experiments bypass the selective filter and are obligatorily encoded in VWM. The obligatory encoding of new items into VWM may then lead to overwriting of items already stored. However, to explain why memory performance is particularly poor for items that are overlapped by a subsequent mismatching item, one must assume that the overwriting that occurs as a result of encoding new information into VWM can be location-specific, and that mismatches in item identity relative to matches produce a larger overwriting effect.

To this end, we propose that the object-file framework forwarded by Kahneman et al. (1992) may be of value in understanding these effects. According to this framework, the visual system binds together featural information into a temporary, episodic, memory representation known as an *object-file*. The contents of an object-file can be updated when new perceptual information appears that shares the same spatiotemporal coordinates as an existing object file. In the context of our experiments, items within the memory array may be encoded into object-files that store the bound conjunctions of location and identity features. Responding to the location of an item that overlaps and mismatches the contents of one of the previously established object-files may forcefully update the contents of this object file and overwrite the previous contents. In contrast, responding to the location of an item that overlaps and matches the contents of this object-file would produce little cost. In this way, the above-described overwriting mechanism can be adapted to account for the response-induced binding mismatch deficit.

Another candidate mechanism is retroactive interference. Retroactive interference occurs when information stored in memory is rendered temporarily inaccessible due to competition for retrieval from other information more recently encoded (Keppel, 1968; Postman, 1961; Tulving & Psotka, 1971). A key difference between a retroactive interference account and an overwriting account is that in the latter, the target feature binding from the memory array is corrupted or destroyed upon response to the mismatching letter that replaces the target letter in the memory array. The retroactive interference account assumes only that response to the mismatching letter renders the target feature binding inaccessible.

In the current context, the principle of interference could operate if the encoding of the mismatching letter in the intervening display were to impede the retrieval of the target feature binding from the memory array. Attempts to remember the location of a target item from the memory array may cue the retrieval of all feature bindings involving that target letter. As the location-identity binding for the intervening display target was encoded more recently than that for the memory array target, it might have an advantage in a competitive retrieval process, resulting in a form of "occlusion" of the target location-identity binding.

Additional research will be needed to distinguish between retroactive interference and overwriting accounts of the present results.

Relationship to Consolidation Processes

To this point, we have suggested that the response-induced binding mismatch deficit is a consequence of disruptive processes that occur after the encoding of the memory array items. Indeed, the overwriting and retroactive interference accounts outlined above attribute this deficit to the disruption of memory representations, and the temporary inaccessibility of such representations, respectively. However, another possibility is that the mnemonic impairments observed here reflect impoverished encoding as a result of responding to the intervening display (Chun & Potter, 1995; Jolicoeur & Dell'Acqua, 1998; Stevanovski & Jolicoeur, 2007). According to this account, encoding items into VWM is a capacity-limited process that requires central resources. As such, it could be that executing a speeded response to the target item in the intervening display draws on the limited central resources that are needed to successfully consolidate the items from the memory array into VWM. There is reason, however, to doubt this explanation: the mnemonic impairment observed in the current experiments was specific to the item from the memory array that was subsequently overlapped by a responded-to mismatching letter. The specificity of this impairment casts doubt on the idea that the observed deficit reflects poor encoding, as there is no obvious reason why disrupting the consolidation process would affect memory for only one of the memory array items.

Nonetheless, one way to rule out the consolidation hypothesis would be to manipulate the temporal interval between the memory array and the intervening display and assess the impact of this manipulation on the response-induced binding mismatch deficit. Given that some estimates of the duration of consolidation are as long as 500 ms (Chun & Potter, 1995; Jolicoeur & Dell'Acqua, 1998), the observation of a response-induced binding mismatch deficit when this temporal interval is extended beyond 500 ms would constitute strong evidence against the consolidation hypothesis. Indeed, follow-up work from our laboratory has demonstrated that the response-induced binding mismatch deficit can be measured when the temporal interval between the memory array and intervening display is 1500 ms (Fiacconi & Milliken, in prep.).

Implications for Theories of VWM

Most studies investigating visual memory have assumed that the properties of the VWM system are revealed by experiments in which visual information is presented, and participants' ability to retain that visually presented information across time is measured. That is, the bulk of research on this topic has focused on understanding visual memory performance in *static* conditions where discrete amounts of information are presented and tested. Although this approach has undoubtedly yielded useful insights, there has been little research directed at the question of how we coordinate information in visual memory with the demands of concurrently perceiving and acting on the world around us. This is an important question given that perceptual input is constantly in flux, and efficient interactions with the world around us require the ability to integrate fluidly our current experience with any information that may be held online in memory. These issues have only recently begun to be studied in the visual memory domain (Ueno et al., 2011a,b; Makovski, Watson, Koutstaal, & Jiang, 2010). The unique contribution of the present research to that emerging literature is to point out some profoundly disruptive effects of responding to perceptual input on the retention of online information in visual memory.

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Table 1. Mean percentage of localization response errors for Experiments 1-4. Error rates are reported as a function of whether the target item in the intervening display overlapped one of the items from the memory array and whether or not a mismatch or a match occurred at the overlapped location. The Location-change heading refers to trials on which participants responded to the location of an intervening display target when that target appeared in a previously unoccupied location. The Mismatch heading refers to trials on which participants responded to the location of an intervening display target that mismatched the previous contents of that location. The Match heading refers to trials on which participants responded to the location of an intervening display target that matched the previous contents of that location.

Experiment	Location-change	Mismatch	Match
1	4.1	3.9	3.1
2 (Go Trials)	4.1	4.1	3.4
2 (No-go Trials)	0.2	0.2	0.2
3	3.4	3.1	5.2
4	4.8	3.7	-
5 (Go Trials)	3.1	2.9	-
5 (No-go Trials)	0.2	0.1	-

Figure 1.

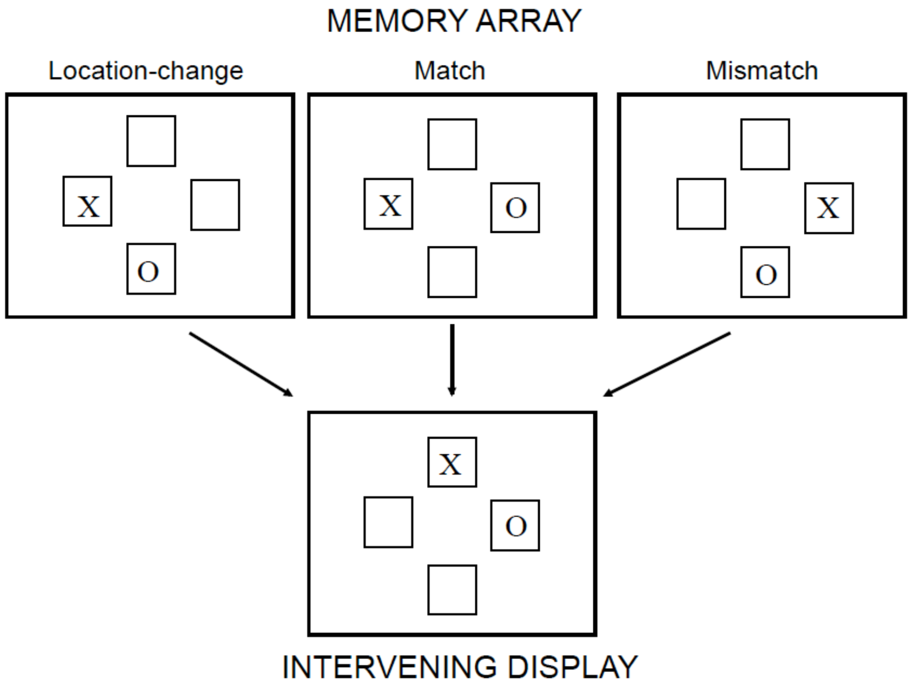

MEMORY ARRAY
Location-change
Match
Mismatch
X
O
X
O
X
O
X
O
INTERVENING DISPLAY

Figure 2.

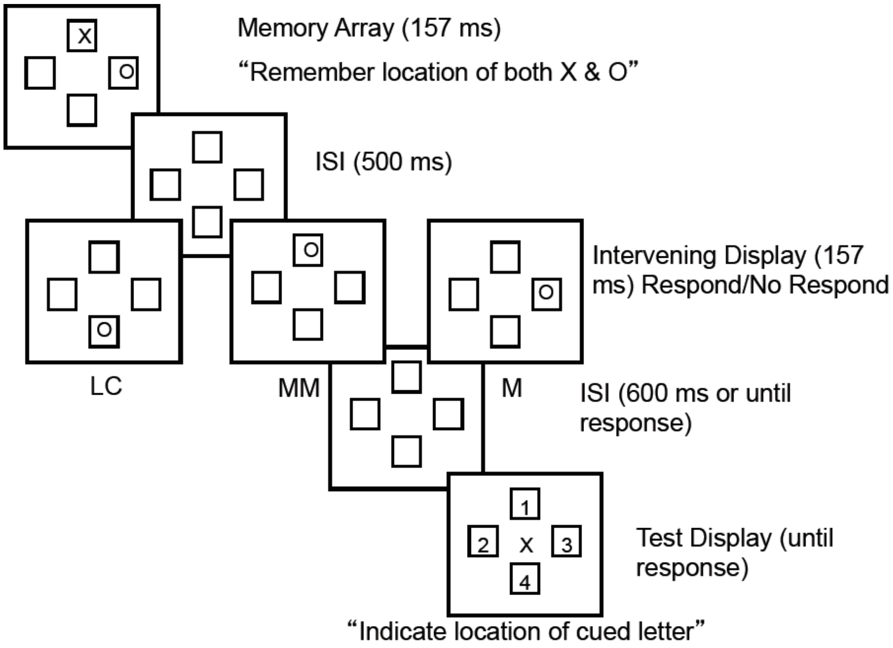

X
O
Memory Array (157 ms)
“Remember location of both X & O”
ISI (500 ms)
O
O
O
Intervening Display (157 ms) Respond/No Respond
LC
MM
M
ISI (600 ms or until response)
1
2
X
3
4
Test Display (until response)
“Indicate location of cued letter”

Figure 3.

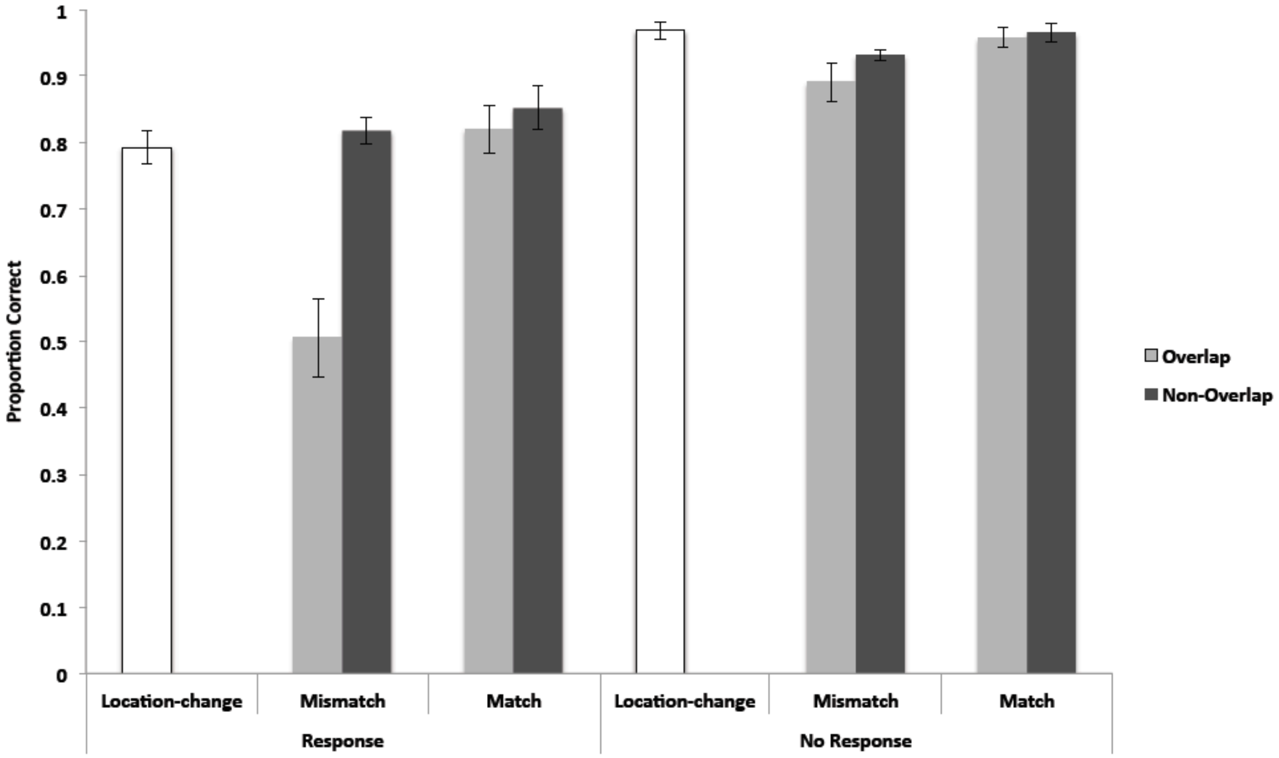

Proportion Correct
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Location-change
Mismatch
Match
Location-change
Mismatch
Match
Response
No Response
Overlap
Non-Overlap

Figure 4.

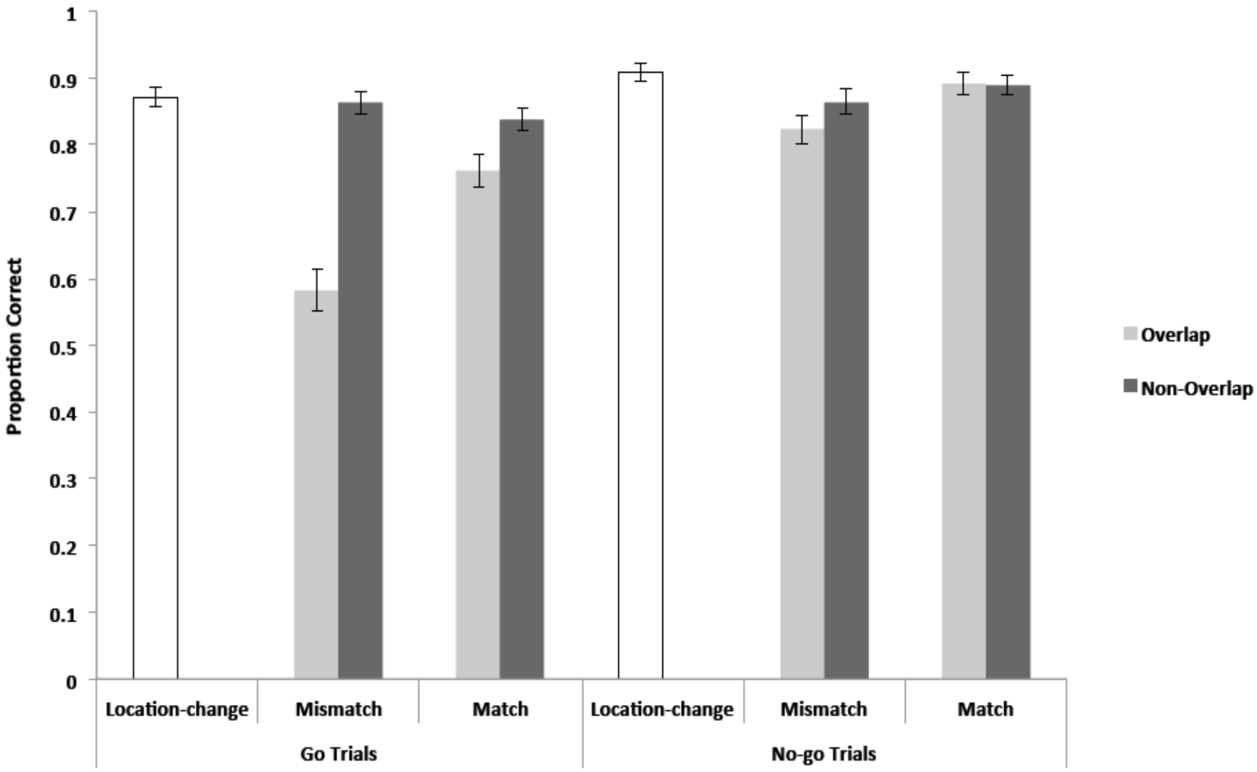

1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Proportion Correct
Location-change
Mismatch
Match
Location-change
Mismatch
Match
Go Trials
No-go Trials
Overlap
Non-Overlap

Figure 5.

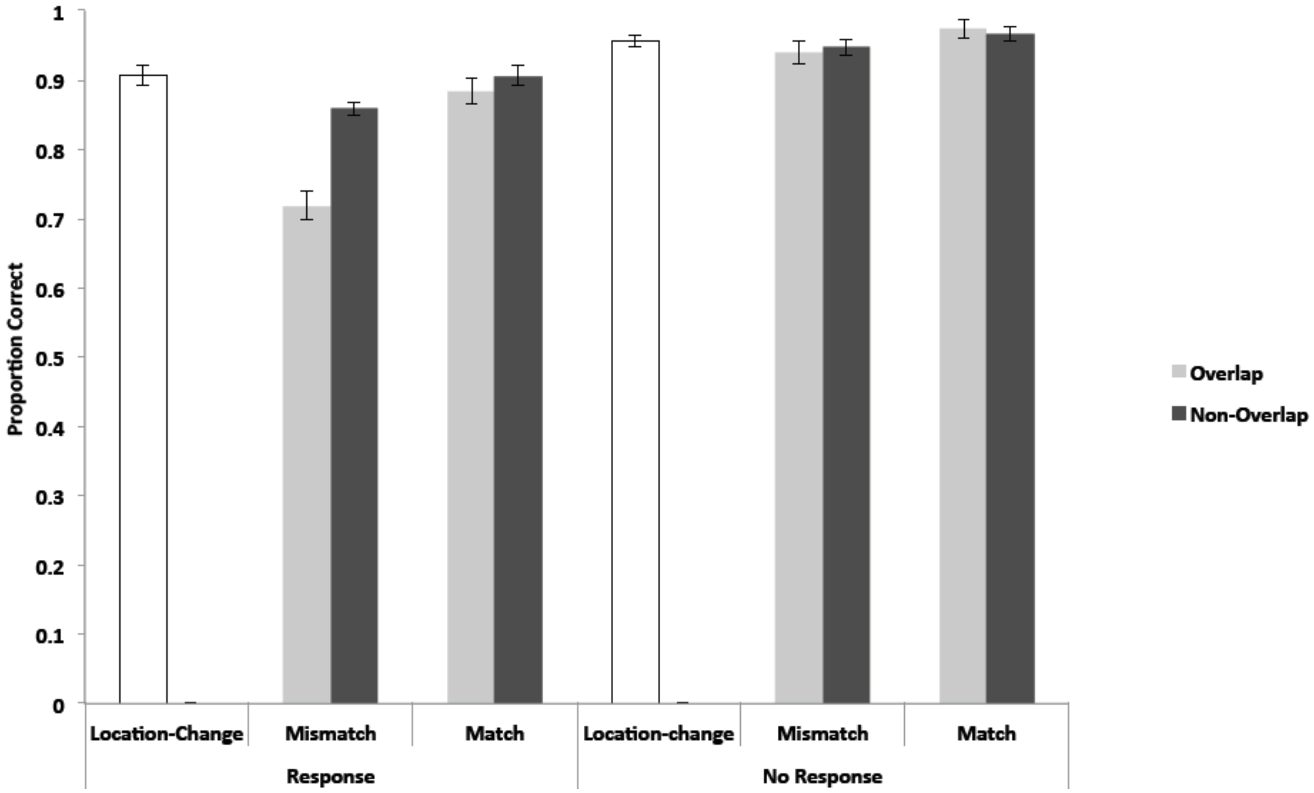

1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Proportion Correct
Overlap
Non-Overlap
Location-Change
Mismatch
Match
Location-change
Mismatch
Match
Response
No Response

Figure 6.

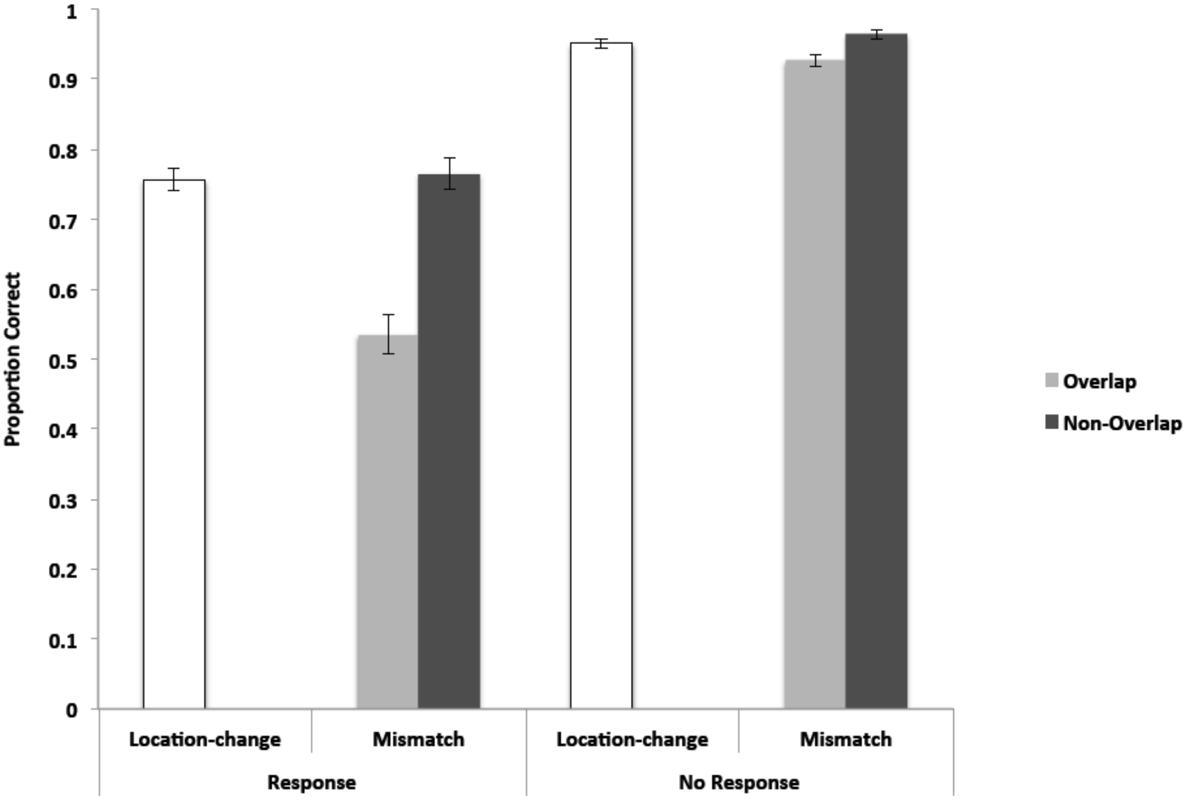
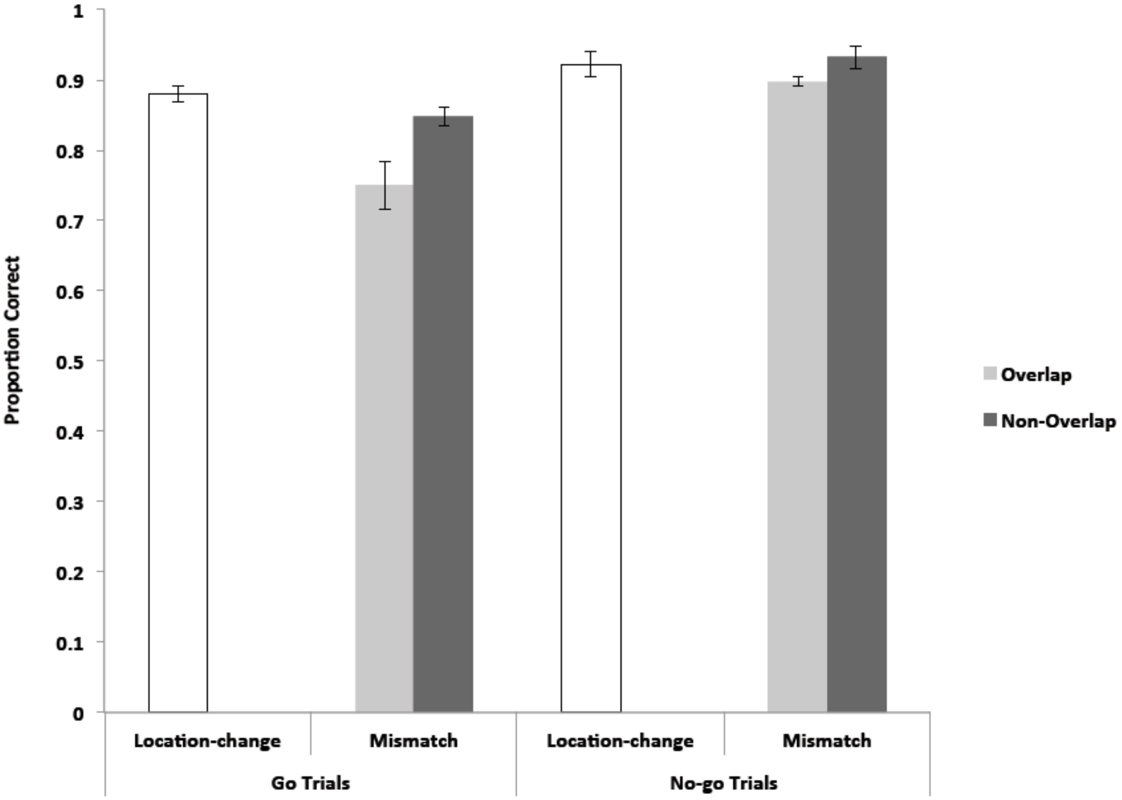

1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Proportion Correct
Location-change
Mismatch
Location-change
Mismatch
Response
No Response
Overlap
Non-Overlap

Figure 7.


Proportion Correct
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Location-change
Mismatch
Location-change
Mismatch
Go Trials
No-go Trials
Overlap
Non-Overlap

CHAPTER 5: General Discussion

The binding together of distinct elements of an experience is a fundamental process that is operative across many domains within human cognition. In the Introduction to this thesis, I outlined the role of binding processes in the perception, memory, and human performance literatures, as well as their theoretical contribution to each domain. Given the ubiquity of binding processes, the primary objective of this thesis was to explore the contribution of these processes to an important, yet poorly understood aspect of human psychology: the generation of explicit awareness of statistical structure. In particular, this thesis was concerned with the role of perceptual binding processes in mediating explicit awareness of strong trial-to-trial statistical regularities in a performance task context, and the mechanism by which such binding processes exert their influence.

The empirical work presented in Chapter 2 stemmed from a surprising result reported by Vaquero et al. (2010). In their study, it was found that a remarkable number of participants were unable to verbalize a strong contingency in which the location of a particular visual character predicted that a subsequent mismatching target item to which a response was to be made would appear in that same location. The experiments in Chapter 2 were aimed at understanding the factors that mediate explicit awareness of this strong statistical regularity. One hypothesis that might explain the observed lack of awareness is that participants may not have attended to the predictive visual information prior to the onset of the target. To test this hypothesis, I conducted a series of experiments in which participants were forced to attend to the predictive information on each trial. Although inducing participants to attend to this information raised the level of contingency awareness somewhat, there remained a large proportion of participants who were nonetheless unaware of the contingency. The relative ineffectiveness of these attentional manipulations led to the consideration of the possibility that awareness of the contingency was obscured not by inattention, but by the mismatch in perceptual identity between the predictive item and the subsequent target item. Indeed, it was found that when there was a match in perceptual identity between the predictive item and the subsequent target item, the level of observed contingency awareness was quite high.

The experimental results reported in Chapter 2 strongly suggested that the relation between location-identity bindings across successive displays had a substantial influence on participants' ability to verbalize a strong trial-to-trial statistical regularity. In particular, very few participants were capable of verbalizing a strong contingency in which the location of a target item was predicted by the location of a preceding predictive item that mismatched in identity with the subsequent target item. The goal of the empirical work presented in Chapter 3 was to understand why the presence of a contingency defined by a high proportion of location-identity binding mismatches was associated with such low levels of explicit awareness. The experiments reported in this chapter were inspired by recent work in the visual working memory literature demonstrating that online memory representations can, under certain circumstances, be vulnerable to disruption from subsequent sensory input that mismatches these representations (Allen, Baddeley, & Hitch, 2006; Alvarez & Thompson, 2009; Ueno, Allen, Baddeley, Hitch, & Saito, 2011; Ueno, Mate, Allen, Hitch, & Baddeley, 2011; Wheeler & Treisman, 2002). Applied to the problem of contingency awareness, these findings suggest the possibility that poor contingency awareness in the presence of location-identity binding mismatches could reflect the cumulative result of trials on which responding to the target item disrupts memory for the location of the predictive character from the previous display. If it were the case that responding to the target item disrupted memory for the location of the predictive character, then it would be particularly difficult for participants to become aware of the predictive relation between these two items. Experiment 3 in Chapter 3 was designed to test this hypothesis. The results from this experiment provided support for the idea that explicit awareness of contingencies defined by a high proportion of location-identity binding mismatches is linked to the mnemonic deficits associated with responding to the target item on these trials. The specificity of this mnemonic deficit was quite striking – responding to an item that spatially overlapped and mismatched in identity a prior item resulted in very poor memory for this item only.

Although the mnemonic deficit reported in Chapter 3 was quite large, there remained a number of open questions with respect to the nature of this deficit. The purpose of Chapter 4 was to shed light on some of these questions. One issue addressed in this chapter is whether this deficit was a consequence of responding per se to the mismatching target item, or whether simply attending to the target item was sufficient to produce impairment. To answer this question, I conducted a go/no-go experiment in which participants had to decide for each trial to respond or withhold a response to the target item based on its color. The key property of this task is that on both go and no-go trials participants had to attend to the target item, but a response was required only on go trials. Therefore, if simply attending to the target item was sufficient to produce the mnemonic deficit reported in Chapter 3, this deficit should be observed on both go and no-go trials. It was found, however, that this deficit occurred on go trials only, suggesting that executing a response toward the target item was crucial in producing this effect. Subsequent experiments in this chapter ruled out the possibility that this deficit could be explained by encoding-related biases, as the removal of such biases did not eliminate this mnemonic deficit. Finally, the presence of this deficit did not seem to depend on the similarity between the items in the predictive display and the items in the target display. Together, the results of the experiments reported in Chapter 4 highlight a profound mnemonic impairment for visual feature bindings when a response is executed to subsequent visual input that mismatches the feature bindings held in memory.

Taken as a whole, the experiments reported in this thesis suggest that the relation between feature bindings across successive visual events can have profound consequences for awareness of the statistical structure between those events. Furthermore, it seems that this awareness is intimately linked with the processes that coordinate the integration of prior experience and ongoing perceptual input.

The Relation Between Contingency Awareness, Phenomenology, & Memory

It is a well-known fact that humans are capable of acquiring sensitivity to statistical structure even in the absence of awareness of this structure (Chun & Jiang, 1998; Fiser & Aslin, 2002; Nissen & Bullemer, 1987; Reber, 1967; Turk-Browne, Junge, & Scholl, 2005). Although explicit awareness of such relations is not always necessary for statistical learning, there is ample evidence to suggest that awareness of statistical relations can often influence how these learned regularities manifest in behavior (Cheesman & Merikle, 1986; Jimenez, Vaquero, & Lupianez, 2006; Vaquero, Fiacconi, & Milliken, 2010). An example of this principle was reported by Vaquero et al. (2010), who demonstrated that explicit awareness of a predictive relation between two visual events produced a qualitatively opposite pattern of behavior to that observed when there was no such awareness. This finding, together with others, suggests that, while not necessary for learning, awareness of contingencies can have important consequences for how this learning is expressed in behavior.

Despite the importance of explicit awareness of statistical structure in understanding behavior, there has been little research directed at the question of how such awareness arises (but see Frensch, Haider, Runger, Neugebauer, Voigt, & Werg, 2002; Runger & Frensch, 2008). Consequently, there is a relatively poor understanding of the factors that govern the acquisition of explicit awareness. One of the primary contributions of this thesis, then, is to shed light on some of the processes that might be crucial in generating awareness of statistical relations. More specifically, I propose that contingency awareness in the current experiments reflects a complex interaction between perceptual binding processes and their accompanying phenomenological and mnemonic consequences. In the remainder of this section, I will outline a sketch of how this interaction might work.

Recall that in the present contingency learning experiments, participants were exposed to a series of trials on which they were presented with two successive visual displays. The structure of the experiment was such that the location of the target item in the second display appeared in the same location as the predictive item in the first display on 75% of the trials. Following the completion of the experiment, participants were then asked to estimate the proportion of trials on which the target item in the second display had appeared in the same location as the predictive item from the first display. Therefore, in order to be classified as 'aware' of this predictive relation, participants would have to accurately reflect back on their experience throughout the experimental session in order to correctly estimate the proportion of such trials. An important question, then, is why participants were so accurate in their reflection when the predictive item in the first display matched the identity of the subsequent target item, relative to when there was a mismatch in identity between these two items.

To answer this question, I propose that the object-updating processes described by Kahneman et al. (1992) play an important role in mediating contingency awareness in the current experiments. The object-file framework forwarded by these authors was initially designed to account for performance in priming contexts. By this account, performance does not reflect the activation/inhibition of abstract representations, but rather is driven by a retrieval process initiated upon the onset of new perceptual input that is to be responded to. This new input is said to rapidly retrieve an episodic memory representation of preceding perceptual information that shared the same spatio-temporal address. Responses to new perceptual input are then facilitated to the extent that there exists a match in featural content between the new input and the retrieved memory representation. A good match in featural content is thought to allow the perceptual system to fluently integrate prior memory representations with ongoing perception, while poor matches in featural content are thought to result in a time-consuming, laborious updating process. Although originally designed to explain priming behavior, I suggest that the object-updating processes described above may also have consequences for phenomenological experience. In particular, the fluent integration associated with matches in featural content between retrieved memory representations and new perceptual input could produce a phenomenological impression of perceptual fluency, whereas poor matches in featural content could produce an impression of perceptual dis-fluency.

Applied to the contingency learning experiments reported in this thesis, the onset of the target item in the second display might cue the retrieval of the perceptual information that appeared at this location in the previous display. If the identity of the retrieved item matches that of the target item, the perceptual system would then fluently integrate these two events, resulting in a phenomenological impression of perceptual fluency. In contrast, if the identity of the retrieved item mismatches that of the target item, the perceptual system would engage in a laborious updating process that would result in a phenomenological impression of perceptual dis-fluency. By this view, the relation between the location-identity feature bindings across the two displays has important phenomenological consequences.

How might these assertions help to explain the high levels of contingency awareness observed when there were a large proportion of trials containing a match in the location-identity binding between the predictive item in the first display and the target item in the second display? If it is assumed that participants experience a subjective sense of perceptual fluency for each trial on which there was a match in identity between the predictive item and the subsequent target item, then upon post-experimental reflection, participants might easily recall that a large proportion of trials contained a location-identity repetition. A similar logic might explain why levels of contingency awareness were so low when there were a large proportion of trials containing a mismatch in the location-identity binding between the predictive item and the subsequent target item. Presumably, the absence of the experience of perceptual fluency on such trials would make it difficult for participants to appreciate the frequent occurrence of these trials. Therefore, upon post-experimental reflection, participants are likely to grossly underestimate the frequency with which such trials occurred. In sum, contingency awareness in the present task is largely a product of the accumulation of instances in which the perceptual system fluently integrates two successive events on the basis of a match in featural content. According to this account, the onset of the target item cues the retrieval of the prior item at that location, and the perceptual system then attempts to integrate these two events. Explicit awareness of a high proportion of trials on which there is a repetition of location and identity could then arise if one assumes that this integration process is accompanied by a phenomenologically salient experience of location-identity repetition.

The proposed phenomenological consequences associated with matches/mismatches in feature bindings across successive visual events closely parallel the mnemonic consequences associated with these bindings. Recall that in Chapters 3 and 4, it was found that memory for the location of an item from the first of two successive displays was profoundly impaired when participants had to respond to a subsequent target item that mismatched in identity, but shared the same spatial location as this item. In contrast, memory for the location of an item from the first of two successive displays remained accurate when participants had to respond to a subsequent target item that matched in identity, and shared the same spatial location as this item. These observations fit well with the idea that matches in location-identity bindings between successive visual events are accompanied by a phenomenological impression of perceptual fluency, whereas mismatches in these bindings are not. Indeed, it seems likely that the perceptual fluency experienced in the presence of binding matches would coincide with accurate memory for the location-identity binding of the first item. Similarly, the absence of such experienced fluency associated with binding mismatches is consistent with the fact that memory for the location-identity binding of the initial item is quite poor in this condition. Whether contingency awareness is mediated by the trial-to-trial mnemonic consequences of binding matches/mismatches, or by the nature of the phenomenological impression associated with these matches/mismatches remains to be determined. Irrespective of this issue, the results reported here point to the possibility that the relationship between feature bindings across successive visual events has a similar influence on memory and phenomenology.

The Relation Between Memory, Phenomenology, & Performance

It is also worth mentioning that the experimental results reported across Chapters 2, 3 and 4 point to an interesting interplay between memory, phenomenology, and performance. Recall that for trials on which there was a binding mismatch, memory accuracy for the item that was subsequently overlapped was poor, explicit awareness of a high proportion of such trials was absent, and localization responses to the target item were also slowed (see Experiment 1 in Chapter 3, and Experiment 1 in Vaquero et al., 2010). In contrast, for trials on which there was a binding match, memory accuracy for the item that was subsequently overlapped was quite accurate, explicit awareness of a high proportion of such trials was near ceiling, and localization responses to the target item were facilitated (see Experiment 4 in Chapter 2). The observed correspondence between memory, phenomenology, and performance in the current tasks suggests the possibility that, at least under certain circumstances, all three of these measures may be subserved by a common cognitive process.

What might this common process be? I propose that an event integration process underlies the observed correspondence between memory, phenomenology, and performance. Specifically, conditions that promote the integration between perceptual events (such as matches in feature bindings) also lead to accurate memory, perceptual fluency, and fast performance. In contrast, conditions that prevent such integration (such as mismatches in feature bindings), lead to poor memory, perceptual dis-fluency, and slow performance. It should be noted, however, that although intriguing, these ideas are highly speculative. Future research will be necessary to verify these ideas, and to better understand the relation between memory, phenomenology, and performance.

Implications for the Visual Working Memory Literature

One of the contributions of this thesis was to examine the influence of responding to subsequent perceptual input on memory accuracy for visual information. Although others have noted that memory for feature bindings in particular seem to be vulnerable to disruption from subsequent perceptual input (Allen, Baddeley, & Hitch, 2006; Alvarez & Thompson, 2009; Ueno, Allen, Baddeley, Hitch, & Saito, 2011; Ueno, Mate, Allen, Hitch, & Baddeley, 2011), the experiments in this thesis are the first to demonstrate that in addition to disruption from subsequent perceptual input, memory for a very small number of feature bindings can also be disrupted by subsequent action. Note that many routine daily tasks involve the online maintenance of information in memory together with concurrent action. Therefore, an understanding of visual memory behavior in an ecologically valid setting requires an understanding of how online information in memory is coordinated with subsequent perception and action. A better grasp of how this coordination is accomplished will no doubt be of importance in future research on visual memory.

The mnemonic deficits associated with responding to the second of two overlapping visual events that mismatch in identity also have important implications for understanding the processes that govern short-term visual memory. The bulk of research on this topic to date has focused on delineating the properties of a separate visual working memory system that is thought to temporarily store representations of visual input over the course of seconds.

This approach is reflected in the extensive use of the change detection paradigm, in which participants must indicate whether two successive visual displays are the same or different. The basic working assumption in these experiments is that the presentation of an initial display containing visual information results in the formation of a stable representation of this information in visual working memory. Further, accuracy in detecting changes across a subsequent display is taken as a measure of the content and fidelity of the previously formed visual working memory representations. By this view, the subsequent test display simply serves as a tool to probe memory representations, and does not alter these representations in any way. Performance in change detection tasks, then, could be viewed as a window into the representational content of the visual working memory system.

The memory experiments reported in Chapters 3 and 4 challenge some of these basic assumptions. Recall that it was consistently found that executing a localization response to a target that spatially overlapped and mismatched in identity a memorized item resulted in poor memory accuracy for the location at which this item appeared. These findings strongly suggest that, at least under some circumstances, feature bindings held in memory are vulnerable to disruption from subsequent perception and action, and that visual working memory representations may not be as stable as once thought. The fact that the nature of subsequent perceptual and cognitive demands can negatively affect memory accuracy for previously encountered feature bindings also casts doubt on the notion that change detection tasks provide a pure measure of the representational content of visual working memory. The mnemonic deficits reported in this thesis point to the possibility that change detection accuracy may reflect not only the representational content of information held in memory, but also the outcome of the interaction between this stored information and the perceptual content contained within the subsequent test display.

The Role of Short-term Consolidation

Short-term consolidation refers to the idea that encoding perceptual information into short-term memory is a time-consuming, capacity-limited process (Chun & Potter, 1995; Dell'Acqua & Jolicoeur, 2000; Jolicoeur & Dell'Acqua, 1998; Jolicoeur, 1999; Stevanovski & Jolicoeur, 2007). In an influential series of experiments, Jolicoeur and Dell'Acqua (1998) investigated short-term encoding processes using a dual-task procedure in which participants were to discriminate the pitch of an auditory tone that was presented at varying stimulus onset asynchronies (SOA) after the presentation of a string of letter characters that were to be encoded into memory and subsequently recalled. It was consistently found that at short SOAs, the concurrent tone discrimination task resulted not only in poorer recall of the memorized letter characters, but also in slower RTs to the tone. It was also found that RTs to the tone were slower when the string of letter characters was to be memorized compared to a condition in which these characters were to be ignored. The interpretation of these results forwarded by the authors was that encoding information into short-term memory requires central attentional resources. Consequently, when there is competition for these resources from a concurrent task, encoding processes are likely to suffer, thus resulting in poorer memory accuracy. Likewise, such competition would also produce slower RTs in the tone discrimination task. Further supporting this account, Jolicoeur and colleagues have demonstrated that manipulations that increase the central attentional demands of a secondary task produce larger memory impairments and slower RTs to the secondary task.

The idea that concurrent task demands can influence short-term memory performance is clearly relevant to the results from the memory experiments reported in Chapters 3 and 4 of this thesis. In particular, it might be argued that the mnemonic deficits observed in these experiments are not the consequence of disruption or 'overwriting' upon responding to subsequent perceptual input, but rather reflect encoding-related constraints brought about through response-induced central resource depletion. Indeed, the requirement to respond to subsequent perceptual information a mere 500 ms after the offset of the memory array could require the central resources needed to encode the feature bindings in the prior display. It is in fact likely that these encoding-related impairments did play a role in the current experiments given that responding to subsequent perceptual input produced a general mnemonic impairment across all conditions. However, the result of critical interest – poorer memory accuracy for the location-identity binding of an item that was subsequently overlapped by a target item that mismatched in identity – is unlikely to reflect the disruption of consolidation processes for the following reasons. From the perspective of resource-based encoding limitations, it is difficult to see why responding to a mismatching target item would impair memory for the item that was spatially overlapped by this target, relative to the item that was not overlapped by the target. Furthermore, the response-induced memory deficits for the overlapped item were not observed when the subsequent target matched the identity of this overlapped item. Together, these findings suggest strongly that some other process that operates subsequent to the successful encoding of the to-be-remembered items is likely at play in these experiments. Whether the critical process implicated in our studies is one that 'overwrites' memory representations, or simply renders these representations temporarily inaccessible is a question for future research.

Conclusion

One of the key themes in this thesis is that the coordination of successive perceptual events has a wide range of consequences for memory, phenomenology, and performance. One of the factors that seems to be important in mediating this coordination is the relation between feature bindings across these events. When faced with temporally discrete units of input, the job of the perceptual system may be best characterized as classifying the current input along a continuous dimension from familiar to novel. In other words, the system may attempt to decide whether the current input represents an extension of previous input, or rather represents a new distinct event that is independent of the previous input. This correspondence problem may be particularly difficult to solve in the presence of binding mismatches between events, due to the mixed signals delivered to the perceptual system. The work in this thesis highlights the consequences of such mixed signals for memory, phenomenology, and performance, and represents a step in understanding the intricacies of how the perceptual system coordinates the interaction between past and present.

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