Episodic Memory and Visual Search

An Episodic View of Priming Effects in Efficient Visual Search

By

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Abstract

Cognitive psychologists have long known that there are limitations on human information processing abilities. As such we must constantly attend to relevant information in our environment, sometimes for further processing, at the expense of other information. Visual search tasks have been used extensively by researchers who seek to understand the consequences that this selective attention process has on memory. It has been argued that the priming effects observed in efficient visual search tasks reflect specialized, short-term memory representations that differ markedly from the memory representations believed to produce priming effects in other performance tasks. To the extent that this is true, researchers must adopt a necessary level of complexity in terms of the memory models used to explain the full range of human behavior. The empirical goal of this thesis was to provide a rigorous examination of priming effects in efficient visual search, in order to determine whether such effects can be explained by reference to general, well-studied memory mechanisms that have yielded significant explanatory power in other attention and performance tasks. The results of the experiments reported here suggest that general, well-studied memory principles may be a suitable candidate explanation for priming effects in efficient visual search.

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Higher education is a great privilege that too few people will get to experience. I feel truly privileged to have had the opportunity to attempt to satisfy my curiosity about the world, while learning from many exceptional people. I cannot thank or acknowledge everyone in my life who has helped get me to this point, however, I will mention those that directly impacted my ability to complete this thesis.

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in small packages. You have been a constant source of support for me, without which I'm sure I would not have kept my sanity – I hope I can one day return to you the confidence and insights you have given me. Adam ('red dot') Spadaro, good luck with your future career. Our chats about research have always been helpful to me – I'll turn you into a Leafs fan one of these days. Chris Fiacconi, thanks for the questions, the jam sessions, but most of all, for the endless entertainment you provide (FYI - lab meeting is at 10:00 am). Sandra Monteiro, thanks for all the feedback you have given me and good luck with your future career. Mitch LaPointe, the newest member of our lab, I wish you the best of luck in pursuing your Ph.D. (even though you are a Habs fan). I also want to acknowledge the Spanish visitors we have been fortunate enough to have work in our lab over the years. Joaquin, Maryem, Elena ('the lawyer of the devil'), and Juan, you guys have always kept us on our toes and made the lab a fun place to be.

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PREFACE

This is a 'sandwich' thesis. The first empirical chapter (Chapter 2) is published in a peer-reviewed journal. Chapter 3 is the final version of a manuscript that is prepared for submission for publication. Empirical Chapters 4 & 5 are manuscripts that are currently under consideration for publication in peer-reviewed journals. Each empirical chapter represents a single manuscript for which I am the first author and my supervisor is the second author. The remainder of the preface is designed to clarify my contributions to the manuscripts that comprise the empirical chapters of this thesis.

The first empirical chapter is a reprint of Thomson, D.R. & Milliken, B. (2011). A switch in task affects priming of pop-out: Evidence for the role of episodes. *Attention, Perception & Psychophysics*. 73: 318-333. My role in this manuscript included experimental design and programming, data collection (running human participants), and data analysis. I was also the primary writer.

The second empirical chapter is a manuscript entitled: "The Time-Course of the priming of pop-out effect". The order of authorship is: Thomson, D.R. & Milliken, B. My role in this manuscript included experimental design and programming, data collection, and data analysis. I was also the primary writer.

The third empirical chapter is the following submitted manuscript: Thomson, D.R**.** & Milliken, B. (under review). Perceptual distinctiveness Produces long-lasting priming of pop-out. *Psychonomic Bulletin & Review.* Manuscript ID: PBR-BR-11-260. My role in this manuscript included experimental design and programming, data collection, and data analysis. I was also the primary writer.

The fourth empirical chapter is the following submitted manuscript: Thomson, D.R. & Milliken, B. (under review). Contextual distinctiveness produces long-lasting priming of pop-out. *Journal of Experimental Psychology: Human Perception & Performance*. Manuscript ID: 2011-0423. My role in this manuscript included experimental design and programming, data collection, and data analysis. I was also the primary writer.

As a final note to the reader, each empirical chapter represents a manuscript that is intended to 'stand alone' as a published work. As a result, there is a certain amount of redundancy within the theoretical introductions to each empirical chapter that the reader should be aware of. Despite this, the experiments presented within each manuscript are separate and distinct from one another and are intended to address separate, yet complimentary theoretical objectives.

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CHAPTER 1: Introduction

Since the first empirical studies of human memory, researchers have attempted to develop models, or theories that capture the greatest range of human behavior using the fewest number of principles. This thesis is primarily concerned with a modern instantiation of this problem. Specifically, researchers have recently called into question the distinction between memory processes involved in conscious remembering, and those involved in performing. Historically, behavior in memory tasks has been attributed to different cognitive processes, and even different neurological substrates than behavior in performance tasks, which are, nominally, non-remembering tasks. The problem, therefore, can be stated as follows: can memory that is expressed implicitly through behavior be explained by the same memory principles that have been used for decades to explain conscious, explicit remembering?

In order to frame this problem, the first part of the theoretical introduction that follows will describe historical evidence and rationale for the distinction between explicit memory for previously encountered events (episodic memory) and the implicit effects of previous experience on current performance (priming). I will then describe a theoretical framework that has been forwarded to explain both conscious recollection and priming as being mediated by the same cognitive processes. Generally, this theory posits that memory episodes can guide conscious, deliberate remembering, or can be recruited automatically and implicitly to guide performance in non-remembering tasks. I will then undertake a selective review of the attention and performance literature in which this latter theory has been successful in explaining a host of priming phenomena, for which separate and distinct memory mechanisms have been posited. Finally, I will turn to the case of priming in singleton search. This behavioral effect epitomizes the difficulties in explaining human performance within the same theoretical framework as human memory.

The empirical objective of this thesis is to assess whether priming in singleton search requires the adoption of memory principles that are separate and distinct from those used to explain other behaviors in human memory and performance, or whether such priming effects can indeed be explained via reference to pre-existing theoretical principles that have been successful in explaining a wide range of memory phenomena in humans. It is therefore necessary to undertake a rigorous empirical investigation with respect to the predictions of an episodic retrieval theory of priming in singleton search. If little or no support for such a theory can be observed, then adopting more complex memory models (that attribute priming to memory mechanisms other than those used to explain nominal remembering) may be required.

The Distinction Between Priming and Episodic Memory

Empirical investigations into human memory have demonstrated a broad range of capabilities in healthy normal subjects that have been categorized and differentiated from one another based on a number of characteristics. For example, the type of information being retrieved, whether retrieval is accompanied by awareness, the mechanisms of forgetting, and the particular ways prior experiences are accessed, have led researchers to distinguish between different ‘types’ of memory. This has led to the idea that there are actually multiple memory systems in the brain, many of which are supported by distinct neurological substrates (e.g., Tulving, 1972; Squire, 1992). The multiple systems view of memory has largely been supported by empirical dissociations in normal subjects (Tulving, 1993; 1995), as well as selective memory impairments observed in amnesiac subjects (Scoville & Millner, 1957). Other researchers however, have argued that the observed dissociations simply reflect differences in how memory is accessed, and that memory is actually sub-served by a single unitary system, for which there are different types of memory retrieval processes (see Blaxton, 1989). While this processing view is more recent in the memory literature, the separate systems view has guided empirical investigations into the nature of human memory for several decades and yields a lot of explanatory power over observed behavioral effects. As such, the separate systems view is largely responsible for the historical distinction between memory that is expressed via priming and memory that is expressed through deliberate attempts to remember. The evidence and theoretical rationale for this distinction will be discussed before considering whether priming and nominal remembering can be explained as simply different expressions of prior experience that result from the same underlying memory system.

One of the first distinctions between types of memory to be noted explicitly is the declarative, non-declarative distinction. Declarative memory encompasses any information that can be explicitly retrieved and produced. Non-declarative memory, on the other hand, describes memories that are expressed indirectly, via behavior, and are not accompanied by awareness of either the original learning of the information, or the expression of that information (see Squire, 1992). Nominal remembering therefore is to be considered an expression of the declarative memory system, whereas priming is to be considered an expression of the non-declarative system. These two broad classifications have since been sub-divided further, resulting in several different memory sub-systems underlying human behavior. For example, Tulving (1972) argued for the division of declarative memory into episodic and semantic memory systems. Episodic memory, according to Tulving, reflects the deliberate and conscious recollection of a personally experienced event, together with contextual information and the temporal relations among aspects of the retrieved event (Tulving, 1972; 1989, also see Baddeley, 2004). Semantic memory, on the other hand, reflects the recollection of facts and general knowledge. Thus, even if we restrict our discussion of memory to conscious remembering, it is argued that episodic retrieval is to be reserved only for recollection of the original encoding event. That is, within conscious remembering, memories that are episodic in nature contain source information, whereas semantic memories do not. Support for this distinction comes from recognition memory tests in which participants can make two kinds of 'old' judgments to previously studied items. 'Remember' judgments are argued to reflect the episodic system, in that the participant remembers seeing the word in the study phase with high confidence, whereas 'know' judgments are argued to reflect the semantic system, in that the item seems familiar to the subject, but explicit recollection of the initial exposure at study is absent (Tulving, 1993). This means that, under a multiple systems view, each encoding event results in the simultaneous activation of several memory systems (i.e. episodic and semantic) but that information can be retrieved from these systems independently (Tulving, 1995).

Tulving has formalized the multiple memory systems hypothesis in what is referred to as the Serial, Parallel, Independent (SPI) model of memory (Tulving, 1995). This model gets at the idea that a single encoding experience can result in many different forms of retrieval of a given piece of information. This model delineates at least five different memory systems, all of which are activated at encoding, but not necessarily at retrieval. These systems include the procedural memory system, the Perceptual

Representation System (PRS), semantic memory, working memory and episodic memory. From this classification scheme, it is clear that episodic memory is not only to be distinguished from semantic memory, as was previously argued (Tulving, 1972; 1983), but also from priming, which reflects the operation of the PRS (see Tulving & Schacter, 1990; Schacter, 1992). It is therefore necessary to consider exactly how priming is conceptualized within a multiple memory systems framework, before considering whether priming can indeed be explained via reference to the principles of episodic memory, which is the primary purpose of this thesis.

Broadly speaking, priming refers to the enhanced identification of a given stimulus, following a previous exposure to that same stimulus. While priming effects can be observed between conceptually related, or semantically related stimuli, this broad definition primarily refers to perceptual priming, which will be the focus of our discussion. Perceptual priming, hereafter simply referred to as priming, is typically measured as a decrease in response latency to a previously encountered percept. Thus, priming is operationalized here as the difference in reaction time to a repeated compared to a non-repeated stimulus. This effect has been shown numerous times in human cognition, and is observed in (but not limited to) picture naming (Mitchell & Brown, 1988, Cave, 1997), word naming (Durso & Johnson, 1979), spatial localization (Posner, Cohen & Rafal, 1982), and face identification (Bruce, Burton, Carson, Hanna & Mason, 1994). Priming therefore seems to be a fundamental consequence of perception that facilitates subsequent interactions with the environment.

Historically, as well as more recently, priming has been interpreted within the separate systems framework of human memory. While priming has been argued by some to reflect a specialized form of procedural learning (see Tulving 1995), there seems to be a general consensus among many researchers that priming certainly reflects the operation of a memory system that is separate and distinct from episodic memory (Tulving, 1985; Tulving & Schacter, 1990; Squire, 1992; Tulving, 1995; Hamman & Squire, 1997; Schacter & Buckner, 1998; Wiggs & Martin, 1998, Squire, 2004). For example, the observation that amnesiac patients demonstrate comparable perceptual priming to control subjects on word-stem completion and identification tasks, but show a marked deficit on recognition memory and explicit recollection (Scoville & Milner, 1957; Hamman & Squire, 1997), has led to the conclusion that priming reflects a memory system that relies on a neural substrate other than the medial temporal lobes, which are significantly damaged in amnesiacs. As a result of this, priming has been argued to reflect the operation of the PRS, which represents only the form and structure of a visual percept (Squire, 1992) and does not benefit from 'deep' encoding (see Craik & Tulving, 1975) in the way that explicit, or episodic recollection does. The PRS is argued to be a pre-semantic memory system, in which priming occurs independent of any recollection (Tulving & Schacter, 1990). As such, the PRS is argued to have evolved earlier than the episodic memory system (Tulving, 1995), which, does involve recollection (Tulving, 1985) and also develops fully, earlier in the life span than episodic memory (Wiggs & Martin, 1998). A schematic depiction of the different types of memory, under the separate systems view is shown in figure 1.

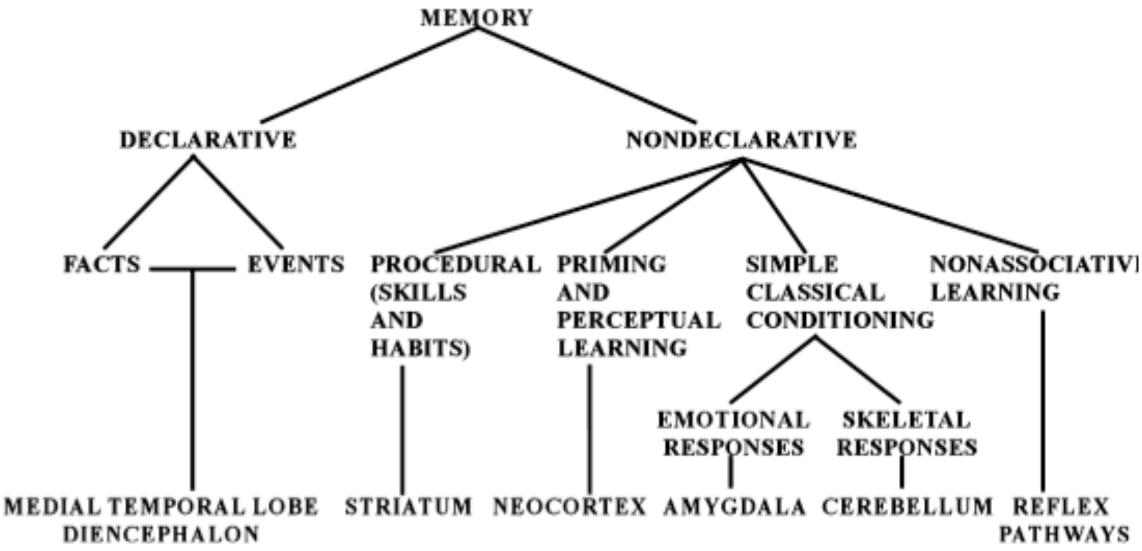

Figure 1. A depiction of the various memory systems and their corresponding neurological substrates. Episodic memory (Events) and Priming are shown as distinct systems/structures in the hierarchy. Taken from Squire (2004), reprinted with permission.

It is clear that within the separate systems view of human memory, priming reflects the operation of a specialized memory system that differs from the episodic system in terms of phenomenology, underlying neural mechanisms, evolutionary trajectory, developmental trajectory and the way information from each system is accessed. Contrary to the retrieval of previously encountered episodes, priming is argued to reflect temporary neuronal changes in brain areas other than the medial temporal lobes. Evidence for this contention comes from fMRI and PET studies in which decreased blood flow is observed in response to previously encountered stimuli compared to novel stimuli (Schacter & Buckner, 1998). Thus, the primary mechanism of priming, under the separate systems view, is repetition suppression of neuronal connections (Wiggs & Martin, 1998). This fits well with the idea that priming occurs in the absence of recollection and is largely supported by data showing that priming effects are not affected by interference from other experiences in the way that explicit episodic memories are (Wiggs & Martin, 1998).

Priming effects in human performance tasks therefore, are argued to represent an effect of previous experience on current performance that is wholly distinct from classic remembering. When we deliberately engage in the retrieval of a prior experience we are attempting to recall a particular episode in which contextual information as well as the temporal relations among events within the episode are recalled (Tulving, 1972; Tulving, 1985). By comparison, when we attend to, and make a response or action to a simple visual percept, we are not engaged in memory retrieval, but are simply asked to perform. As such, prior experiences affect current performance and action, not by deliberate, or even indirect recollection, but by temporary suppression of neuronal connections in the brain, which persist for a short period of time (Hamman & Squire, 1997; Wiggs & Martin, 1998). This qualitative distinction between episodic recollection on the one hand, and priming on the other, has guided research into attention and memory in recent years and has even led some researchers to posit that (at least some) performance tasks do not involve memory at all (Horrowitz & Wolfe, 1998). While this distinction holds a lot of explanatory power, it is possible that it results in a human memory model that is unnecessarily complex. For example, some researchers have forwarded an account of episodic retrieval that can occur implicitly and automatically, even when there are no deliberate attempts to remember (Logan, 1988; Hommel, 1998). This modified view of episodic retrieval has since been applied to a host of performance tasks in which priming effects are typically observed, and so might represent a means by which priming and episodic retrieval can be thought of as resulting from the same underlying memory system. Before turning our discussion to some notable performance tasks in which episodic theories have been successful in explaining priming effects, it is first necessary to assess the characteristics of, and the rationale for, an episodic retrieval view of priming in non-remembering tasks.

Episodic Memory and Performance

The idea that episodic memory representations can be created and retrieved without intention, and thus can guide performance in non-remembering tasks, has gained empirical support in recent years. This idea serves as a more parsimonious alternative to the separate systems perspective in which priming effects and episodic recollection are considered wholly distinct from one another. Although priming in the context of performance tasks is typically an effect of prior experience on behavior (in the absence of awareness) and episodic recollection is typically considered an explicit process, the other qualitative properties of priming and episodic memory may actually be very similar. The basic properties of a memory episode, outside of explicit awareness, include: perceptual as well as action-related and goal-related information, the temporal relations among events within the episode and contextual information (Tulving, 1972; 1985; Squire, 1992). By comparison, repetition priming is argued to reflect temporary changes in firing thresholds for neuronal connections in parts of the brain that represent perceptual features (Hamman & Squire, 1997; Wiggs & Martin, 1998). If it can be shown that priming effects observed in performance tasks are driven by the recruitment of bound, or 'integrated' representations that contain perceptual, contextual and action related information, then it can be argued that priming and explicit recollection both rely on the recruitment of episodic memory representations. We will first review the argument for implicit recruitment of episodic memory representations in performance tasks before looking at a few well-studied priming effects in which this view has gained empirical support.

Hintzman (1976) argued that in a performance task, each stimulus presentation results in the creation of a unique 'trace' in memory. As a result of this, subsequent presentations of the same stimulus result in the creation of multiple traces, which represent each unique experience. While somewhat general in terms of a theoretical framework for understanding the mechanisms of priming, this idea constitutes a marked divergence from predominant theories at the time, in which repeated stimulus presentations were argued to alter the activation thresholds of abstract units that represent stimulus features (Morton, 1969). While these ideas were primarily developed to explain repetition effects in tasks such as lexical decision, which were prominent at the time, they have since been augmented and expanded upon to explain repetition priming and skill acquisition more generally. Similar ideas were also relied upon to explain expertise in the domain of decision making. For example, accuracy of medical diagnosis was shown to depend on the similarity of prior cases to the current case, and that expertise in diagnosis was the result of greater exposure to examples, not the strengthening of complex rules (see Norman, Rosenthal, Brooks, Allen & Muzzin, 1989; Brooks, Norman & Allen, 1991).

Similar to Hintzman's multiple trace theory, Logan (1988) outlined a theory of automatization in which skill acquisition can be explained via reference to individual memory episodes. Generally, automaticity in a given task, such as driving to work, has been argued to occur when stimulus and response mappings are 'strengthened' through experience. As an alternative to this idea, Logan posited that each experience results in the creation of an 'instance' in memory, which is functionally synonymous with the idea of a memory episode. These instances contain perceptual as well as goal and action related information that are bound together in memory, and are subsequently retrieved together implicitly and automatically in the presence of an environmental cue such as a percept or intention that overlaps with the previously encoded instance (Logan, 1988; 1990; also see Morris, Bransford & Franks, 1977). In support of his instance-based account of automaticity, Logan had participants make lexical decisions about words and non-words. Importantly, participants' reaction times decreased as a function of the number of presentations of individual items throughout the experiment. This learning however, did not generalize to novel items, suggesting that particular prior experiences were being recruited from memory to speed performance, and that reaction time decrements were not due to 'general' learning. According to Logan, attention is the mechanism by which some feature of an experience is integrated into an instance. Thus, the primary tenets of instance theory are that encoding into memory is a natural consequence of attention, the same kind of attention that results in encoding also results in retrieval, and each encounter is stored as a separate instance in memory. While simply attending is enough to create a bound episodic memory representation according to instance theory, the degree of attention to a particular feature, together with its relevance to the task will determine the strength of that feature representation in the created instance. Similarly, information at the focus of attention will function as a stronger retrieval cue than information outside the focus of attention. Thus, automaticity as well as priming effects in performance tasks can be thought of as resulting from the implicit and automatic retrieval of individual prior experiences (Logan, 1988; 1990) and may therefore reflect the expression of episodic memory, and not the temporary activation or suppression of abstract units (Morton, 1969; 1979) or neuronal connections in the brain (Schacter & Buckner, 1998; Wiggs & Martin, 1998).

The automatic retrieval of bound information in performance tasks has been demonstrated empirically by Kahneman, Treisman and Gibbs (1992). In their study, participants viewed two letters that appeared in two of four marked objects (squares) on each trial. This prime display was followed by the presentation of a single letter that appeared in one of the four locations. Participants had to respond to the identity of the probe letter on each trial. When the probe letter matched one of the prime letters, response times were faster when that letter appeared in the same location from prime to probe displays (within the same object), than when it appeared in a different location. Kahneman et al. (1992) argued that identity and location information in the prime display were bound together in a memory representation that they referred to as an ‘object-file’, which was subsequently retrieved by attending to the probe display. To the extent that information from memory matches current perception, performance is facilitated, to the extent that information from memory only partially matches current perception, performance is slowed. Thus, Kahneman et al. (1992) argued that even in simple letter identification, trial-to-trial priming effects are best explained by the automatic and implicit creation and retrieval of bound representations from memory.

Hommel (1998) added to the notion of object files, by demonstrating that action and response information are also bound together with perceptual features in memory. It was shown, in a simple discrimination task, that performance was facilitated between prime and probe displays when both perceptual and action information matched, than when there was only partial overlap either in terms of perception or action. The observation that partial-match conditions produced slower performance than complete mismatches between prime and probe displays demonstrates that the attended features of a percept are bound together in memory and not represented independently (as in a neural suppression view of priming effects) (Stoet & Hommel, 1999). To get at the idea that action and response information is also encoded into memory in an obligatory fashion, Hommel replaced the term 'object-file' with 'event file'. These event files are qualitatively identical to the instances described by Logan (1988; 1990). Once again, attention is argued to be the mechanism by which information is bound into an event file, with greater attention resulting in a stronger representation in memory. A schematic depiction of the features of a percept being bound into an episodic event file is shown in figure 2.

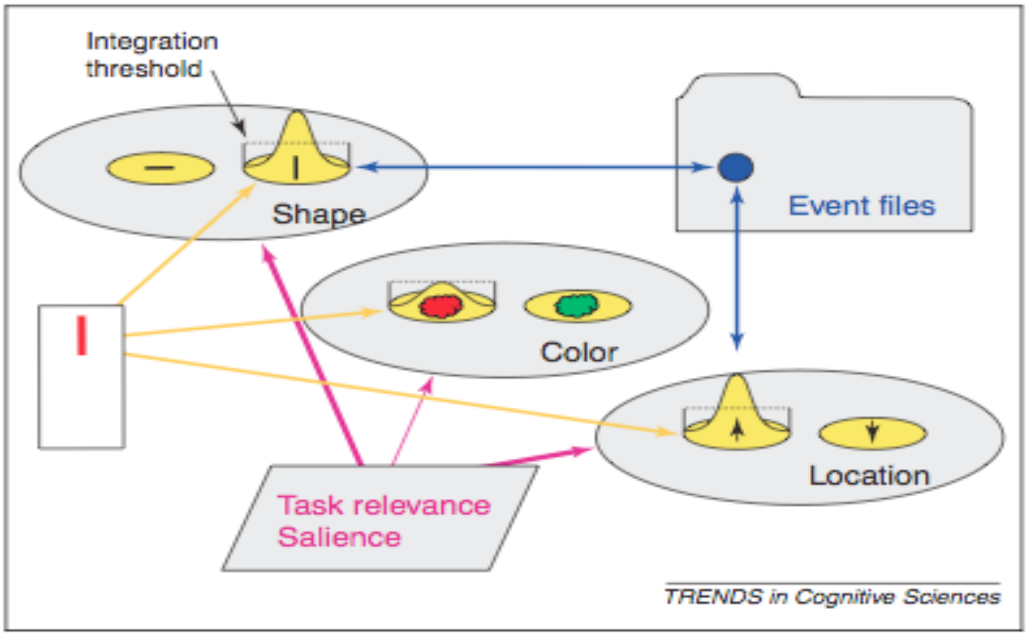

Figure 2. Example of feature integration into an event file. Each feature of a stimulus has a given activation threshold that is set by relevance of the feature to the task. If the threshold for a given feature is reached (via attention), the feature becomes integrated into the event file, or instance. Taken from Hommel (2004), reprinted with permission.

It has been argued that the retrieval of bound episodic representations from memory can occur in tasks that are not, nominally, remembering tasks. These memory episodes are bound representations of previously attended information that are encoded into memory via attention and subsequently retrieved implicitly and automatically when attention is drawn to some aspect of the environment that matches the contents of these episodes. Whether they are referred to as memory traces (Hintzman, 1976), instances (Logan, 1988), object files (Kahneman, Treisman & Gibbs, 1992) or event files (Hommel, 1998), bound episodic representations provide a mechanism with which to interpret inter-trial priming effects within the same theoretical framework as nominal remembering. Before we turn our attention to priming effects in singleton search for which episodic theories have gained little support, we will first undertake a selective review of priming effects in some other notable performance tasks in which episodic theories have yielded significant explanatory power.

Priming Effects in Human Performance

Priming effects seem to be ubiquitous among the many tasks used to measure attentional processes, including Stroop (Stroop, 1935), Flanker (Eriksen, 1995), spatial localization (Posner, Cohen & Rafal, 1982), lexical decision (Rubenstein, Garfield & Millikan, 1970), picture identification (Cave, 1997) and visual search (Maljkovic & Nakayama, 1994; Chun & Jiang, 1998). Despite this, there lacks consensus among the researchers who use such tasks as to whether these priming effects reflect the operation of memory retrieval processes, or simply the temporary strengthening of neuronal connections in different parts of the cortex. Memory retrieval interpretations of priming effects have been forwarded in recent years to account for a range of observations in the attention and performance literature that were previously attributed solely to transient activation or suppression of cortical representations. These explanations however, have been confined to discrete literatures that make use of particular tasks and procedures and as such, there are still a number of priming phenomena for which memory retrieval processes are in doubt. What follows is a selective review of well-studied priming phenomena for which episodic-like memory retrieval operations have been argued to drive performance, including negative priming, task-switching costs, conflict adaptation and inhibition of return.

Memory & Negative Priming

In certain situations, repetition of a previously encountered percept can actually slow performance from one trial to another in non-remembering tasks. Tipper (1985) had participants view two pictures on each trial that were super-imposed on one another. The task was to name aloud the red picture while ignoring the green one. Interestingly, it was found that when the target picture on the current trial matched the distracter picture on the previous trial, performance was slower compared to when there was no relationship between stimuli from one trial to the next. Tipper (1985) described this effect as negative priming and argued that it was the result of active inhibition of the distracting information on one trial that persisted transiently across time. If the current trial requires a response to a previously ignored item, performance is slowed due to the persistence of the inhibitory processing from the previous trial (Tipper, 1985; Tipper & Cranston, 1985). Thus, the suppression of abstract representations was originally posited as the primary mechanism behind negative priming effects and fits nicely with the separate systems view of priming effects described earlier. Indeed, additional studies seemed to support this contention by demonstrating empirically that negative priming effects do decay passively across time, with the most decay occurring in the first second after a response (Neill & Valdes, 1992).

Although Neill and Valdes (1992) demonstrated the seemingly transient nature of inhibitory processing in the negative priming effect, they offered a very different interpretation of these observations. Rather than interpreting the decay of negative priming within the active inhibition hypothesis (Tipper, 1985; Tipper & Cranston, 1985), they argued that negative priming may be due to the retrieval of episodic representations and that as the temporal delay between trials increases, the probability of retrieval of a prior episode decreases, as in Logan's (1988; 1990) instance theory account of priming effects. While the decay of negative priming can easily be interpreted with either an active inhibition or an episodic retrieval account of performance, Neill, Valdes, Terry & Gorfein (1992) found additional evidence for the episodic retrieval account. Neill et al. (1992) had participants localize a target letter that appeared in one of four marked locations on each trial, while ignoring a distracting letter. Negative priming is typically measured in such a task when the target on one trial appears where a distracter letter appeared in the previous trial. Interestingly, they randomly varied the response to stimulus interval (RSI) between trials (either 500 ms or 4000 ms), in order to observe whether the temporal discriminability of the previous trial with respect to the current trial modulates the negative priming effect. Active inhibition theories posit that only the RSI from the previous to current trials should affect priming, whereas episodic retrieval theories posit that when the previous trial is more temporally discriminable from other trials, the probability of retrieval is increased, and so negative priming should be greater (see Baddeley, 1976). Importantly, Neill et al. (1992) found that negative priming was greatest when the ratio of previous-to-current RSI was large compared to when it was small, and thus argued that negative priming benefits from a reduction in proactive interference from other trials. This is easily accounted for, and indeed predicted by episodic retrieval theories of priming effects, but is incongruous with active inhibition theories.

Further support for an episodic retrieval explanation of negative priming was observed by DeSchepper and Treisman (1996), who found that negative priming could be observed across 200 intervening items and up to delays of one month. Again, this is very difficult to reconcile with a theory of negative priming that posits decay of active inhibition processes within seconds post-response. Finally, Neill (1997) had participants identify a central letter that was flanked by two distracter letters of a different identity. Negative priming was observed when the central target letter on one trial was the same as a flanking distracter letter on the previous trial. Crucially, the distracter letters could appear simultaneously with the target letter, or after a 400 ms delay. Results showed that when the temporal onset of target and distracters from one trial to the next was the same, negative priming was greater than when distracter onsets differed between trials. Neill (1997) argued that this reflected an increased probability of retrieval of the previously encoded episode because target-distracter onset functioned as a contextual cue. To the extent that temporal context repeats from one trial to the next, there is a greater match between current perception and the most recently created memory episode, and so automatic retrieval is facilitated.

Thus, negative priming represents a behavioral effect observed in the context of certain performance tasks that was originally considered to reflect the transient inhibition of abstract processes. But taken together, the empirical evidence to-date seems to suggest that an episodic retrieval explanation of negative priming holds greater explanatory power (for a review of this idea, see Mayr & Buchner, 2007). More broadly, this represents a particular concrete example of priming effects that can be explained via reference to general episodic principles, and need not require separate and distinct mechanisms, or systems to account for behavior.

Memory & Task-Switching

Jersild (1927) was the first to empirically demonstrate a cost associated with performing two different tasks, one after the other, compared with performing the same task twice. Interestingly, this 'shift-cost' was only observed when the same stimuli were used for the two tasks (i.e. performing either a parity judgment or subtraction task on a given numerical stimulus). Typically considered an index of cognitive control operations and executive function, task-switching has been studied extensively in recent years. Trial-to-trial switch costs ('local' switch costs) have been argued by some researchers to reflect activation from the competing task-set, that persists across time (Rogers & Monsell, 1995). This idea, referred to by Allport, Styles and Hsieh (1994) as 'task-set inertia' posits that in order to perform a given task, the relevant task-set must be activated in working memory while the irrelevant task-set, must be temporarily suppressed. The activated task-set remains active until it is suppressed via cognitive control operations, in response to a task switch. Other researchers however, have argued for a memory interpretation of local task-switch costs.

Mayr and Kliegl (2000) have argued that task-sets are not activated or suppressed in working memory, but rather, that task-sets are retrieved from long-term memory. This idea posits that switch costs reflect the time required to retrieve the relevant task-set from memory, and therefore predicts that switch costs should vary as a function of the retrieval demands of the relevant task-set. In order to test this, participants performed one of four judgments related to concrete nouns that were presented on each trial. These judgments could have low retrieval demands (living/non-living, or larger/smaller than a soccer ball) or high retrieval demands (location on the screen, or color of the item from a previous study phase). Importantly they found that switch costs were significantly larger when switching to a task-set that had high, relative to low, retrieval demands, suggesting that task-switch costs may reflect memory retrieval processes. Further support for this contention has been provided by Waszak, Hommel and Allport (2003) who had participants read a word or name a picture in response to picture/word Stroop stimuli. Interestingly, they found that task switch costs (from picture naming to word reading) were significantly larger when the current stimulus had been presented previously in the context of the other task. Furthermore, this effect was observed even with 100 intervening items between the picture naming and word reading trials for a given stimulus. Waszak et al. (2003) interpret their results within an instance-based account of task shift costs, in which stimuli, responses, and goal-related (task-set) information are bound (integrated) in memory and are subsequently retrieved when that same stimulus is presented again.

Taken together, recent empirical evidence supports the idea that costs associated with switching from one task to another may reflect the retrieval of bound episodic memory representations related to task-sets, that are retrieved by the current stimulus. These episodes may contain perceptual, contextual, and even response-mappings that are compatible with the demands of the current task, but task-set information (or cognitive control operations) that are incompatible with the current task, thus causing an increase in response latencies. Further support for this comes from Mayr and Bryck (2005), who were able to eliminate switch costs (in error %) when color and orientation tasks were associated with separate locations in space. They argued that location information is bound into memory on each trial and therefore serves as a retrieval cue for task appropriate (location specific) memory episodes. Task switch costs may therefore be better explained via reference to episodic retrieval of bound information from memory than by transient activation and suppression of abstract task representations.

Memory & Conflict Adaptation

Priming effects have also been observed in other notable performance tasks, for which episodic explanations have recently been forwarded. For example, compatibility effects (difference in reaction time between congruent and incongruent stimuli) have been shown to vary as a function of the congruency of the previous trial (Gratton, Coles & Donchin, 1992). Gratton et al. (1992) had participants respond to the identity of a central letter that was flanked by two other letters on the left and right, that could either match or mismatch the target letter. Interestingly, compatibility effects (slower response times for mismatch versus match stimuli) were significantly smaller if the previous trial was a mismatch trial compared to when it was a match trial. This effect, termed ‘conflict adaptation’, was argued to reflect trial-to-trial adjustments in cognitive control settings that reflect stimulus-response association strengths. For example, in the presence of a mismatch trial, stimulus-response associations are strengthened for the task-relevant stimulus dimension, and weakened for the task-irrelevant stimulus dimension. The persistence of these weights allows for faster responding to conflict in the next trial, but produces a slowing if the next trial is a match trial, thus reducing the compatibility effect. Others have argued, however, that these control settings do not persist across time, but rather, are encoded into a bound episodic memory representation on each trial, that is subsequently retrieved on the next trial (Spape & Hommel, 2008).

Spape & Hommel (2008) had participants perform a vocal stroop task in which they responded to the pitch of an auditory tone (‘hi’ or ‘low’) while ignoring a simultaneously presented auditory word ('hi' or 'low'). Interestingly, the speaker of the auditory word (male or female) could either repeat or switch from one trial to the next. Significant conflict adaptation effects were obtained using this procedure, but importantly, such effects were only observed when the speaker of the irrelevant, auditory word, repeated from one trial to the next. Spape and Hommel (2008) interpret their results within an instance-based account of conflict adaptation effects (Logan, 1988; 1990). They argue that stimulus, response, and contextual information are all bound together in memory on each trial, and that these memory representations are retrieved on subsequent trials. The degree of overlap between the current trial and the contents of the memory for the previous trial determines the probability of this retrieval process. This contention fits well with other findings, showing that conflict adaptation is highly specific to particular stimuli and task demands from one trial to the next (Notebaert & Verguts, 2008; Funes, Lupianez & Humphreys, 2010).

Conflict adaptation effects therefore represent another example of a priming effect in human performance for which the principles of episodic memory seem to hold the most explanatory power. These effects were initially conceptualized as reflecting transient cognitive control operations, in which stimulus-response associations were strengthened or weakened from one trial to the next. It now seems reasonable however, that such control operations are actually encoded into memory on each trial, and subsequently retrieved if the match between current and prior performance is high.

Memory & Inhibition of Return

Inhibition of return (IOR) refers to the behavioral phenomenon in which attending and responding to an object is faster and more efficient at novel locations compared with previously attended locations. Posner and Cohen (1984) were the first to describe this effect empirically. In their task, a spatial cue appeared at one of two peripheral locations (marked with boxes on the left and right of the screen) for which no response was required. Following that, a target dot appeared at either the cued or un-cued location that required participants to respond to its location as quickly and accurately as possible. Interestingly, response times were faster for targets appearing at un-cued compared to cued locations. This behavioral effect was argued to reflect the transient inhibition of attention to previously viewed locations, presumably as an adaptive mechanism to prevent inefficient 're-sampling' of the environment when searching for something in space (Posner & Cohen, 1984).

Tipper, Grison and Kessler (2003) called into question the notion that IOR reflects transient inhibitory states that rapidly decay post-response. In their procedure, the peripheral locations were replaced with unique faces taken from a large stimulus set, upon which a cue dot would appear, followed by a target dot on either the cued or the un-cued face. Using this procedure, IOR was observed that lasted for several minutes and survived several intervening trials. These researchers argued that the re-instantiation of the task-irrelevant faces cued the retrieval of inhibitory processes that were bound into memory. Thus, IOR has been argued to reflect the involuntary encoding of information into memory that is subsequently retrieved if the appropriate cues are present (Grison, Tipper & Kessler, 2003; also see Grison, Paul, Kessler & Tipper, 2005). This view differs significantly from the explanation of IOR forwarded by Posner and Cohen (1984) and reflects an episodic view of IOR in which stimulus, response, and task-related processes are bound together in memory.

Additional support for episodic retrieval explanations of IOR has been provided by Wilson, Castel and Pratt (2006). These researchers replicated the findings of long-term IOR found by Grison et al. (2003) but did so using a procedure that more closely resembles that used by Posner and Cohen (1984). Instead of using unique (and contextually rich) faces as location placeholders, they used the standard left and right boxes, but added two diamond shaped boxes (one on the top and one on the bottom). Participants performed 6-8 spatial cueing trials on two of the locations, followed by one trial on the other two locations. IOR was observed that survived the 6-8 intervening trials in the common locations, suggesting that spatial distinctiveness is all that is required to produce long-term IOR. As a result of this, Wilson et al., (2006) revised the memory retrieval hypothesis forwarded by Grison, Tipper and Kessler (2003). They argued that stimulus, response and location information are integrated into an episodic memory representation on each trial and that it is the mismatch in response information between the retrieved episode and the demands of the current stimulus that manifests in increased response latencies (IOR).

It can therefore be argued, that like negative priming, task-switching, and conflict adaptation, inhibition of return represents yet another priming effect in human performance for which the general principles of episodic memory seem to hold a lot of explanatory power. These episodic explanations represent a qualitatively different view of priming effects than the various forms of activation/suppression accounts that were originally forwarded. Although these transient activation/suppression ideas fit well with the separate systems view of human memory, episodic interpretations of priming effects allow us to entertain a human memory model that is far less complicated (is more parsimonious with respect to the underlying memory representations that drive human remembering) and which can likely be relied upon to explain future discoveries in the domain of inter-trial priming. One such effect that has thus far eluded a convincing episodic explanation is the priming of pop-out effect in singleton search. Before describing this effect, and the empirical work on this effect that comprises this thesis, we will first consider the arguments for and against memory retrieval processes in visual search in general.

Memory and Visual Search

In the last three decades, visual search has received considerable study from cognitive psychologists. Visual search is a necessary part of interacting with our environment. It may involve mundane tasks such as looking for a friend in a crowd and searching for the milk in the refrigerator, or more important tasks such as scanning an x-ray for the presence of a tumor and searching luggage for deadly weapons at airport security. While the processes that contribute to efficient visual search can inform us on how humans select relevant information from a cluttered visual scene, such processes also inform us about the way that attention is deployed in our environment. It is only recently however, that a role for memory in visual search has been posited. We will briefly consider some of the mechanisms and processes believed to be at work in various visual search tasks before turning to the case of priming in singleton search, which will comprise the empirical basis of this thesis.

Treisman and Gelade (1980) argued for two distinct processing mechanisms at work in visual search. These are argued to reflect sequential stages in processing that occur while one is searching for a particular target stimulus among distracters. The 'pre-attentive' stage of processing, it is argued, first analyzes the visual scene 'holistically', such that all items in the display are assessed in parallel. Areas of the visual scene that are particularly salient will draw attentional resources to allow for more focused 'attentive' search, in which items are analyzed individually until the target is identified. While both of these sequential processing stages may occur in complex search, certain types of search task are argued to rely solely on pre-attentive, or parallel, processing. For example, when searching for a target that differs from homogeneous distracters along one salient dimension (referred to as a feature singleton), such as color, motion, orientation or size, search latencies do not significantly increase as set size (number of distracting items in the display) increases. This has been argued to reflect the idea that all items in the scene only need to be analyzed in parallel in order to locate the target. By comparison, when a target is defined as a unique combination of features (referred to as a conjunction), such as a red, horizontal bar among blue and red vertical bars and blue horizontal bars, search latencies increase in a linear fashion with increases in set size (Treisman & Gelade, 1980), suggesting that processing must proceed to the attentive, serial stage for target localization.

In a series of experiments, Theeuwes (1991) demonstrated that when participants performed a search for a singleton target defined by shape, they could not avoid having their attention captured by an irrelevant, but salient color singleton that was also present in the display. Despite lots of experience with, and foreknowledge of, the irrelevant feature singleton, participants were not able to over-ride attentional capture, leading Theeuwes to conclude that only stimulus driven (or 'bottom-up') processing occurs in parallel (or pre-attentive) search. Implicit in this conclusion is that prior experience cannot affect performance during parallel search tasks. Horrowitz and Wolfe (1998) also claimed to have found evidence suggesting that there is no role of prior experience (memory) when participants perform a more difficult conjunction search task. In their experiment, participants had to locate a rotated ‘T’ amongst ‘L’s. In one condition, target and distracter displays remained static for the duration of the trial (static condition), while in another condition, the distracter configuration randomly shifted about once every tenth of a second (dynamic condition). Results showed that search efficiency was similar in both the static and dynamic conditions, suggesting that as search unfolds, no memory exists for previously attended items within a trial. Based on these findings, Horrowitz and Wolfe (1998) argued that search is ‘amnesiac’ and that it is driven by neuronal changes in the visual cortex that do not outlast the time frame of visual persistence[1]. Taken together, the results of Theeuwes (1991; also see Theeuwes, 1992) and Horrowitz and Wolfe (1998) suggest that perhaps visual search (whether parallel or serial) does not involve memory. As we shall discuss, observations of priming effects in both conjunctive and parallel search tasks, have cast serious doubt on this assertion.

In a conjunctive search task similar to the one implemented by Horrowitz and Wolfe (1998), Chun and Jiang (1998) had participants locate a rotated T amongst L’s. In their design, a sub-set of displays would repeat across each block of trials, while in the remaining displays within each block, target and distracter configurations were determined randomly. Importantly, search times were significantly faster in the later blocks for repeated target-distracter configurations than for novel ones. This effect, termed ‘contextual cueing’, demonstrated the role of prior experience on current performance in a serial search task, and occurred despite participants’ chance recognition performance in identifying displays as either ‘old’ or ‘new’. Chun and Jiang (1998) argued that bound episodic memory representations of target-distracter configurations were created on each trial, and were recruited implicitly and automatically by repeated displays, thus facilitating target localization. The observation of contextual cueing effects in conjunctive search, as well as trial-to-trial priming effects in singleton search (Maljkovic & Nakayama, 1994), which will be discussed shortly, have led some researchers to refute the claim that visual search is ‘amnesiac’ in nature (see Shore & Klein, 2000 for a review).

The observation of contextual cueing effects in conjunctive visual search demonstrate that individual search trials are encoded into memory and that they can influence behavior a significant amount of time later in an implicit and automatic fashion. Further evidence for the episodic nature of these memory representations comes from work with amnesiacs. Chun & Phelps (1999) demonstrated that amnesiac patients with severe damage to the hippocampus failed to demonstrate contextual cueing effects. This suggests that the hippocampus is crucial for observing contextual cueing, a structure that has been long implicated as mediating episodic retrieval (Tulving, 1985; Squire, 1992). These demonstrations have prompted a revision of the claim by Horrowitz and Wolfe (1998) that visual search is amnesiac. Instead, Wolfe, Butcher, Lee and Hyle (2003) concedes that visual search may have at least a ‘modest’ form of memory, and later argues that visual search probably involves both bottom-up (stimulus-driven) and top-down (memory-based) processing (Wolfe, 2010; also see Kristjansson & Campana, 2010).

While visual search was originally argued to be driven solely by very short-term activations of neurons in the visual cortex, the memory representations that are created during each search experience seem to affect performance in line with episodic retrieval theories. Thus, priming effects observed in conjunctive search (contextual cueing) may be added to the list of notable priming effects for which episodic memory principles hold the greatest explanatory power. Priming effects in parallel search tasks however, present a challenge to episodic retrieval theories of human performance in general. While the existence of such priming effects explicitly demonstrate that memory contributes to parallel search in at least some form, the nature of such memory representations is a topic of considerable debate among researchers who measure these effects. As yet, there is little convincing evidence to suggest that priming in parallel search can be explained by the same episodic principles that have been invoked to explain IOR, conflict adaptation, task-switch costs, negative priming, and contextual cueing. The remainder of this theoretical introduction will briefly describe the priming of pop-out effect in singleton search, an effect which has so far eluded a convincing episodic explanation, and which will be the subject of empirical investigation in the remaining chapters of this thesis.

Priming of Pop-Out

Unlike priming effects in conjunctive search, which have been attributed to the retrieval of bound representations, there is current debate among researchers concerning the nature priming effects in singleton (or parallel) search. Maljkovic and Nakayama (1994) were the first to empirically demonstrate trial-to-trial priming effects in singleton search. In their experiments, participants had to locate an odd colored diamond from amongst two homogeneous distracters and indicate whether the target diamond was truncated on the left or the right (this task was first used to examine singleton search performance by Bravo & Nakayama, 1992). Interestingly, when they analyzed search latencies for odd-colored targets as a function of whether the target-color repeated or switched from the previous trial, repetition priming was observed. That is, response times were faster for repeated relative to alternated targets from one trial to the next. This effect has been termed priming of pop-out (PoP) to get at the idea that even though the target 'pops-out' of the display, and the task is very easy, repeated experience with a given target color can facilitate performance. PoP represents the first clear evidence for memory influences in singleton search, an effect that has been shown to occur implicitly and automatically (Maljkovic & Nakayama, 2000) and lasts for about 5-8 trials (Maljkovic & Nakayama, 1994).

Understanding the nature of the memory representations that drive PoP is an important and current issue in cognitive psychology. On the one hand, if PoP can be explained by reference to the implicit and automatic recruitment of memory episodes, then priming effects in singleton search can be explained under the same parsimonious framework that has been successful in explaining priming effects in other notable performance tasks. On the other hand, if PoP cannot be explained within an episodic framework, then we must adopt a more complex model in order to explain memory influences in the context of performance (non-remembering) tasks. To recap, evidence for episodic retrieval mechanisms in other priming effects has come from demonstrations showing that information is bound (integrated) in memory, that stimulus and response information is strongly linked in memory, that match or mismatch in task-irrelevant context modulates such priming effects, and that these priming effects can be shown to persist longer than a few seconds (the time frame of neural activation/suppression mechanisms). While we will discuss in more detail the relevant empirical findings from the PoP literature that can inform us on this issue in the next three chapters. In general, there is some initial evidence that the memory mechanisms driving PoP may reflect bound representations. Beyond this however, there is little convincing evidence for episodic retrieval mechanisms operating in PoP.

The remainder of this thesis will undertake a rigorous empirical examination of the principles of episodic retrieval in the priming of pop-out effect. Specifically, in chapter 2, I will assess whether non-perceptual, higher-order task demands modulate the PoP effect. In chapter 3, I will directly assess whether PoP decays passively over time, and whether it is affected by the temporal distinctiveness of the most recent search episode. Finally, in chapter 4, I will assess whether task-irrelevant contextual information can produce long-lasting PoP effects. To foreshadow, results demonstrate that while PoP effects do seem to decay passively over time and are not affected by manipulations of temporal discriminability, they are driven by bound (integrated) representations that include stimulus, response, and task-specific information. Furthermore, I will show that when search arrays are presented in salient, unique contexts, PoP can be observed that lasts more than twice as long as has been shown previously. Taken together, I will argue that when singleton search is performed, an episodic memory representation is laid down, and under certain circumstances, the integration of prior episodes with current performance can be observed. In other words, like many other notable priming effects observed in performance tasks, PoP is best explained by the implicit and automatic retrieval of bound episodes from memory.

Footnotes

[1] Visual persistence is the amount of time that a visual percept impinges on the retina after focal attention is withdrawn from the stimulus, or after the stimulus is

removed. The time-frame of such persistence is on the order of 250-300 milliseconds (Neath & Suprenant, 2003).

CHAPTER 2: A Switch in Task Affects Priming of Pop-Out: Evidence for the Role of Episodes

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PREFACE

Chapter 2 presents the results of four experiments in which one of the predictions of an episodic retrieval theory of priming in singleton search is tested. Specifically, implicitly recruited memory episodes (or instances) may contain more than salient perceptual features of a previously viewed search display. To that end we examined whether the response selection task that is to be performed on a pop-out target is encoded in memory on each trial. We employed a task-switching procedure (Rogers & Monsell, 1994) in which priming of pop-out effects could be examined in both task repeat and task switch conditions. It was shown that priming of pop-out effects were significantly diminished when the selection task alternated from trial *n*-1 to trial *n*, relative to when it repeated, even when the perceptual attributes of the search displays remained unchanged (Experiment 4). This is taken as evidence that the memory underlying the priming of pop-out effect can contain more than low-level perceptual information; an initial piece of evidence that episodic-like memory representations may contribute to priming in singleton search.

Abstract

Maljkovic and Nakayama (1994) demonstrated that response times decrease in a pop-out search task when target-defining features repeat from one trial to the next. This priming of pop-out (PoP) effect has been explained by some researchers as reflecting low-level modulations in attentional control settings (Lee, Mozer & Vecera, 2009). The present experiments tested whether a shift in higher order task requirements from trial *n*-1 to trial *n* alters PoP effects. The results of Experiments 1 and 2 demonstrated that a switch in task significantly modulated PoP effects when shape was the relevant pop-out dimension. Experiment 3 failed to show significant modulation of PoP as a function of task switch when the pop-out dimension was color, but the findings of Experiment 4 did show modulation of PoP for color when the relative salience of target and distracters was high. Together, the results strongly support the view that PoP effects can be sensitive to a switch in task, a result consistent with the view that PoP effects are modulated by trial-to-trial episodic integration processes.

The way in which we select relevant information from a cluttered visual scene has been the subject of considerable study in cognitive psychology. A task often used for this purpose is visual search. It is a well-known finding in these studies that some types of search are more efficient than others. For example, when searching for a conjunctively defined target amongst heterogeneous distracters, search times are particularly slow and tend to increase as the number of distracting items in the display increases. On the other hand, when searching for a singleton target amongst homogeneous distracters, search has been shown to be particularly fast and far less sensitive to manipulations of set size (Treisman & Gelade, 1980). This latter observation has been termed pop out, to capture the idea that the target pops out from the field of distracters without requiring an item-by-item search.

Pop out in visual search has often been attributed to low-level bottom-up processes that do not require attention (Treisman & Gelade, 1980). According to this view, the efficient detection of a pop-out target relies on a salience map that serves to draw attention to areas in space that are particularly salient with respect to surrounding perceptual information. In accord with this idea, localization of a pop-out target has been described as “pre-attentive” (Treisman & Gelade, 1980).

A role for memory in pop-out search was demonstrated however by Maljkovic and Nakayama (1994). They asked participants to search for an odd-colored singleton target in the presence of two homogeneous distracting items, and to indicate whether the left or right corner of the target diamond was missing. They demonstrated that responses were faster when the same colored target repeated from one trial to the next than when the target color switched from one trial to the next. Maljkovic and Nakayama called this effect priming of pop-out (PoP), and they noted that it implied that pop-out search is mediated not just by the bottom-up salience map created by the perceptual properties of the current stimulus display, but is also mediated by the past experiences of the observer (Maljkovic & Nakayama, 1994; 1996; 2000). The mechanisms underlying PoP have since been the topic of considerable study, a brief overview of which follows.

PoP effects have been described by some researchers as reflecting the operation of a memory trace that encodes target-defining feature information only. The simple idea here is that memory for the previous target-defining feature can facilitate search if the target in a subsequent display matches the contents of that memory trace (Maljkovic & Nakayama, 1994; 1996, Bravo & Nakayama, 1992). According to this view, this memory trace is implicit in nature, as subjects appear to lack awareness of target and distracting properties of preceding trials (Maljkovic & Nakayama, 2000), and is relatively short-term, as it exerts an influence on search performance for 5-8 subsequent trials (Maljkovic & Nakayama, 1994; Experiment 5). Maljkovic and Nakayama (1994) also demonstrated that these priming effects are not driven by response repetition effects from trial to trial (Experiment 6) and do not depend on the expectations of the observer (Experiment 2), and so concluded that the implicit memory trace for target-defining features exerts its influence at a pre-attentive stage in search, as described by Treisman and Gelade (1980).

While some researchers have gathered additional empirical support for the notion of a memory influence that is specific to target-defining information (Hillstrom, 2000), others have noted that target-irrelevant information can also have an impact on search performance for pop-out targets (Olivers & Humphreys, 2003; Huang, Holcombe and

Pashler , 2004; Kristjansson, 2006; McBride, Leanords & Gilchrist, 2008). Huang et al. (2004) had subjects perform a pop-out search task for an odd-sized target, in which they had to report the orientation of the odd-sized singleton. The color of the target was irrelevant to the task; nonetheless results showed that search times for repeated targets on the task-relevant dimension (size) were further expedited if the task-irrelevant dimension (color) also repeated from one trial to the next. Interestingly, a switch in the target-defining dimension across trials was further slowed by a match in the target-irrelevant dimension. These results seem to indicate that more than target-defining feature information affects pop-out search performance. More recently, Lee et al. (2009), using a procedure similar to Maljkovic and Nakayama (1994), had participants search for an odd-colored target item amongst a set of homogeneous distracters. In one experiment, an irrelevant task was inserted in between search displays. The irrelevant task required participants to indicate which end of a shape presented in isolation was pointed (top or bottom). Crucially, results showed that if the color of the irrelevant shape matched the color of the singleton target on a subsequent search display, search was facilitated. Taken together, the results of these studies require a reconsideration of the mechanisms that mediate pop-out search performance from trial to trial. That is, a theory must be invoked that takes into account more than just target-defining features.

An alternative view that accommodates influences beyond those of target-defining features assumes that PoP effects are best explained by reference to both low-level feature priming and trial-to-trial adjustments in cognitive control settings (Wolfe, Butcher, Lee & Hyle, 2003; Lee et al., 2009). By this account, as attention is drawn to the area of the salience map with the highest activation in the visual scene, there is a relative activation of the feature dimension that defines the target (for example, 'red' gets activated relative to 'green' if the target and distracters are red and green respectively). Devoting attention to this task-relevant feature information necessarily means that other information bound-up in the target object may also be encoded (such as task-irrelevant target shape in a color singleton task). Features that are activated by the target of the current stimulus display are assigned relative weights based on task-relevance, such that the target-defining feature will guide future responding more so than the task-irrelevant feature. This feature priming account of PoP effects posits independent activation and suppression of low-level target and distracter information (Lee et al, 2009; Olivers & Humphreys, 2003). Although the feature priming process is mediated by cognitive control processes, it is related to the original view of Maljkovic and Nakayama in that low-level feature priming processes remain the predominant mechanism responsible for PoP.

A very different theoretical account of PoP assumes that it is best explained not by reference to low-level feature priming, but instead by reference to the operation of episodic memory representations that are created and retrieved on each trial. The study by Huang et al. (2004) described earlier demonstrates an interaction between target-relevant and target-irrelevant feature repetitions from trial to trial. The fact that a repetition of the target-irrelevant color dimension can speed responding on some trials and slow responding on others suggests that the role of that feature is not determined by the nature of the previous trial, as in a feature priming account, but instead is determined by the role played by a given feature on the current trial compared to the previous trial. Huang et al. (2004) argued that this observation is more in line with an episodic retrieval view of priming in singleton search and less so with trial to trial adjustments in cognitive control settings. By this view, the attended-to components of the stimulus display are encoded in a single representation, perhaps in the form of an instance as described by Logan (1988), and the retrieval of this representation on a subsequent trial then affects performance. The precise contribution of the previous trial to current performance might occur in accordance with the memory principle known as transfer appropriate processing (Morris, Bransford & Franks, 1977; see also Neill & Mathis, 1998; Wood & Milliken, 1998; Hommel, 1998 for applications to performance tasks). That is, the perceptual characteristics of the current display may cue retrieval of similar prior episodes. Performance will be facilitated to the extent that the processing operations on the current trial match those retrieved as part of the prior processing episode, with strong benefits for perfect matches and weaker benefits or perhaps even costs for partial matches. In this way, an episodic retrieval account seems suitable to explain inter-trial priming effects in singleton search, in particular complex effects involving target-relevant and target-irrelevant features that might well be difficult to explain by reference to independent and automatic priming of low-level feature representations.

A primary purpose of the present study was to assess the episodic retrieval account of PoP effects. In particular, we were interested in examining predictions such a theory makes that have yet to be subjected to empirical test. It is generally well accepted that episodic memory representations are not limited to the encoding of low-level features and the attentional control settings that lead to the encoding of those features, but rather they include broad task goals of the observer, in line with the transfer-appropriate processing framework (Morris, Bransford & Franks, 1977). For example, episodic accounts of negative priming posit that processes involved in withholding a response to a given stimulus dimension on one trial can slow responding when that same stimulus dimension requires a response on the next trial (Tipper, 1985; Hommel, 1998). In this way, it is conceivable that a current search episode cues the retrieval of feature representations, attentional operations, and other higher-level task-related processes associated with similar prior episodes. If performance in PoP tasks unfolds according to this principle, then a clear empirical prediction is that task-level representations ought to mediate PoP effects.

In previous work on PoP, researchers have manipulated the match between previous and current stimulus displays along both target-relevant and target-irrelevant dimensions, but subjects have always performed the same discrimination task from trial to trial, meaning a single task-set is sufficient for good performance in such tasks. By a feature priming account of PoP, a change in selection task from trial to trial, while resulting in a task-switching cost, should not alter the relative contributions of low-level stimulus repeats and alternations from trial to trial, since the same low-level information is used to guide target localization from one trial to the next regardless of the selection task that is to be performed once that target is localized. By an episodic retrieval account however, the goals of the observer, and therefore the task to be carried out, are bound up in the same episodic memory representation as other low-level target-relevant and target-irrelevant information. By this theory then, task switches should create a partial match between the current and prior processing episodes, thus reducing the degree to which preceding experiences facilitate current action. Thus by repeating or alternating the selection task from one trial to the next in a predictable manner it is possible to examine the role of task-set on PoP effects.

To this end, the primary purpose of the present study was to observe how priming of pop-out effects for singleton targets defined by either shape or color are affected by a predictable switch in the response selection task from one trial to the next. A secondary empirical objective was to observe how repetitions versus alternations of a target-irrelevant stimulus feature affected search from trial to trial. In Experiment 1, subjects searched for an odd shape target and then made either a horizontal/vertical judgment about a line inside that shape, or made a 'T'/'L' discrimination to a letter inside the odd shape. In Experiment 2, the color of the stimulus displays either repeated or switched from trial to trial in a random manner, in order to assess the contributions of target-irrelevant information to search performance. In Experiment 3, subjects searched for an odd color target, with the aim of assessing whether priming effects for color-defined targets are more robust to a switch in task. To foreshadow, the results of Experiments 1 and 2 demonstrated that a task-switch reduced the magnitude of PoP effects for shape, while the results of Experiment 3 showed no such modulation of PoP for color. Experiment 4 demonstrated that a task-switch can indeed reduce PoP effects for color, but this modulation interacted with the relative salience of targets and distracters.

Experiment 1

The purpose of Experiment 1 was to test how PoP effects are affected by a switch in task. Subjects searched for an odd-shaped target amongst seven homogeneous distracters and reported either the orientation of a line contained within the odd shape or the identity of a letter contained within the odd shape. Priming of pop-out effects (the difference in response time between target feature repetitions and alternations) were analyzed both within and between tasks, to validate the present paradigm's ability to measure such effects within task, and to compare PoP effects within and between tasks. If PoP is mediated solely by low-level feature priming, then a switch in task should not significantly affect the magnitude of PoP. However, if PoP effects are mediated by episodic memory representations created on each trial, a switch in task could create a functionally significant mismatch between the current and prior trial, resulting in significantly smaller PoP effects between tasks relative to within task.

Method

Participants. The participants were 20 undergraduates (7 male, 13 female) at McMaster University with normal or corrected to normal vision. Mean age was 18.2 years (7 male, 13 female). Participants received either course credit or $5 for a half hour of participation.

Procedure. Participants were seated in front of a computer screen and were instructed that upon stimulus onset they were to locate the odd-shaped item in the eight-element circular display, which contained one circle and seven squares on half of the trials and one square and seven circles on the other half of the trials. An AABB task switching procedure was used, in which the task to be performed is dictated by where on the screen the search array appears (Rogers & Monsell, 1995). Half of the participants performed a line orientation judgment when the displays appeared in the top two quadrants of the screen and letter discrimination when the displays appeared in the bottom two quadrants of the display, and this assignment of tasks to position was reversed for the other half of the participants. Once a stimulus was responded to, the next search array appeared after a 500 millisecond blank interval in the location adjacent to the previous array in a clock-wise manner, such that where the next display would appear as well as which task was to be performed was perfectly predictable. The responses for both tasks were mapped to the same keys such that a ‘horizontal’ or ‘L’ response required pressing the ‘Z’ key and a ‘vertical’ or ‘T’ response required pressing the ‘/’ key. An example of the procedure is shown in Figure 1a. Subjects were explicitly told about the predictable task repetitions and alternations and were told to be as fast and accurate as possible when doing both tasks. The first 12 trials were practice trials to familiarize subjects with the tasks and stimulus-response mappings. Response times as well as errors were recorded for an additional 388 trials, for a total of 400 trials. Upon completion, participants were debriefed on the nature of the task and given the opportunity to ask questions.

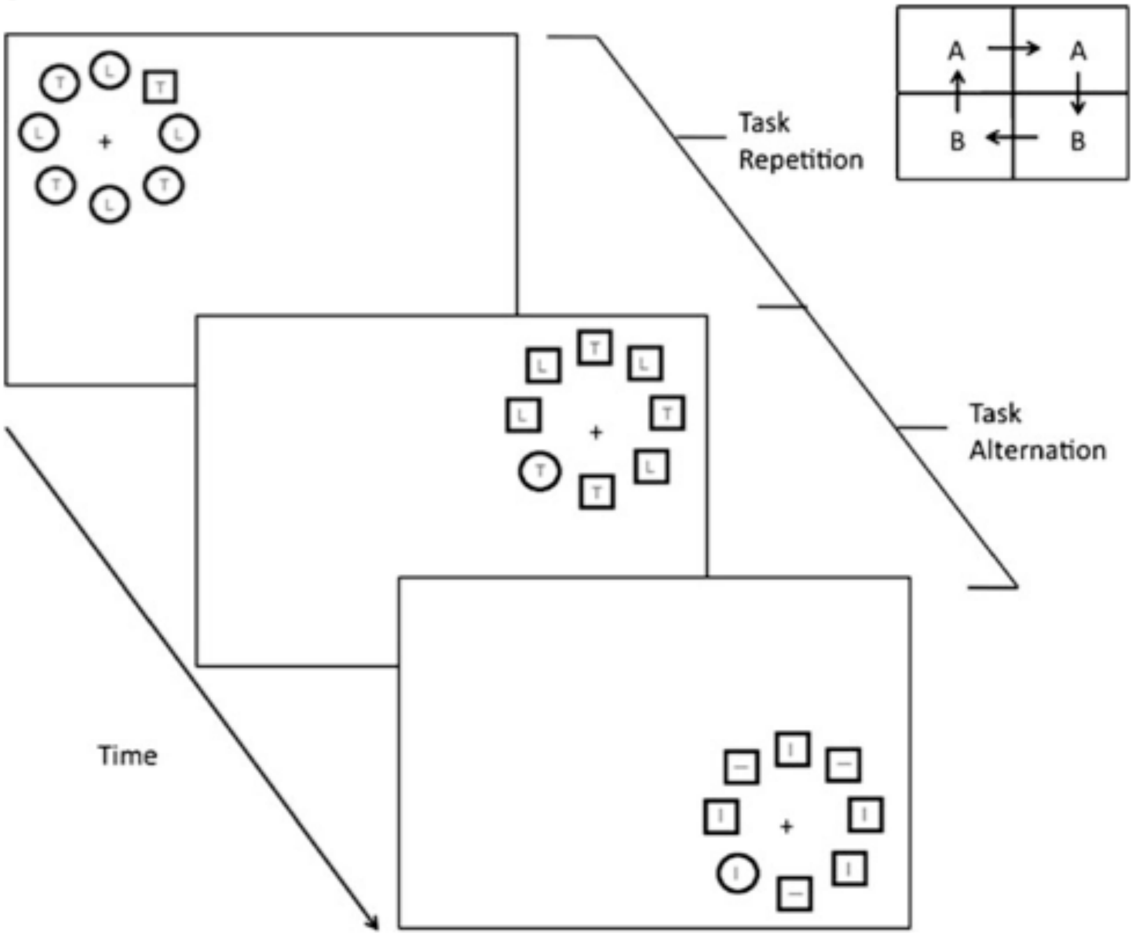

Figure 1a. Displays a sequence of 3 potential trials in which participants locate and respond to the odd-shape in the display. A task repetition as well as an alternation is depicted. Stimulus displays remained on the screen until a response was made and the next stimulus appeared in the adjacent quadrant after an inter-trial interval of 500ms.

Stimuli and Apparatus. Subjects were seated approximately 50 cm away from a computer screen with their index fingers poised over each of the two response keys. Each stimulus display contained eight shapes. Each shape subtended a visual angle of about 1.1 degrees and the entire stimulus display subtended a visual angle of about 6.5 degrees, with a fixation cross that subtended about 0.6 degrees. For the horizontal/vertical discrimination task, the shapes each contained a single vertical or horizontal line that subtended a visual angle of about 0.8 degrees. For the T/L discrimination task, the shapes contained either a single letter T or a single letter L that subtended a visual angle of about 0.6 degrees. Displays appeared in one of four quadrants of the computer screen (although quadrants were not visibly marked on the screen) and remained until response, which was initiated via a key press. The responses 'horizontal' and 'T' were mapped to the Z key and the responses 'vertical' and 'L' were mapped to the / key on the keyboard. Stimuli were presented on a 15-inch Sony CRT screen. Display elements were created and presented using Presentation Software.

Results

Only the trials on which correct responses were made were submitted to the response time analysis. As each experimental condition is contingent on the nature of the previous trial type, response times and errors for trials immediately following an error response were also excluded from analysis. All remaining RTs were submitted to an outlier procedure that excluded RTs based on outlier criteria that varied as a function of cell size (see Van Selst & Jolicoeur, 1994). This analysis eliminated less than 2.5% of the RTs. Mean RTs were then computed from the remaining observations. These mean RTs and corresponding error rates were submitted to a repeated measures analysis of variance that treated target repetition (target-repeat/target-switch) and task repetition (task-repeat/task-switch) as within-subject factors. Mean response times are shown in Figure 1b and mean error rates are shown in Table 1.

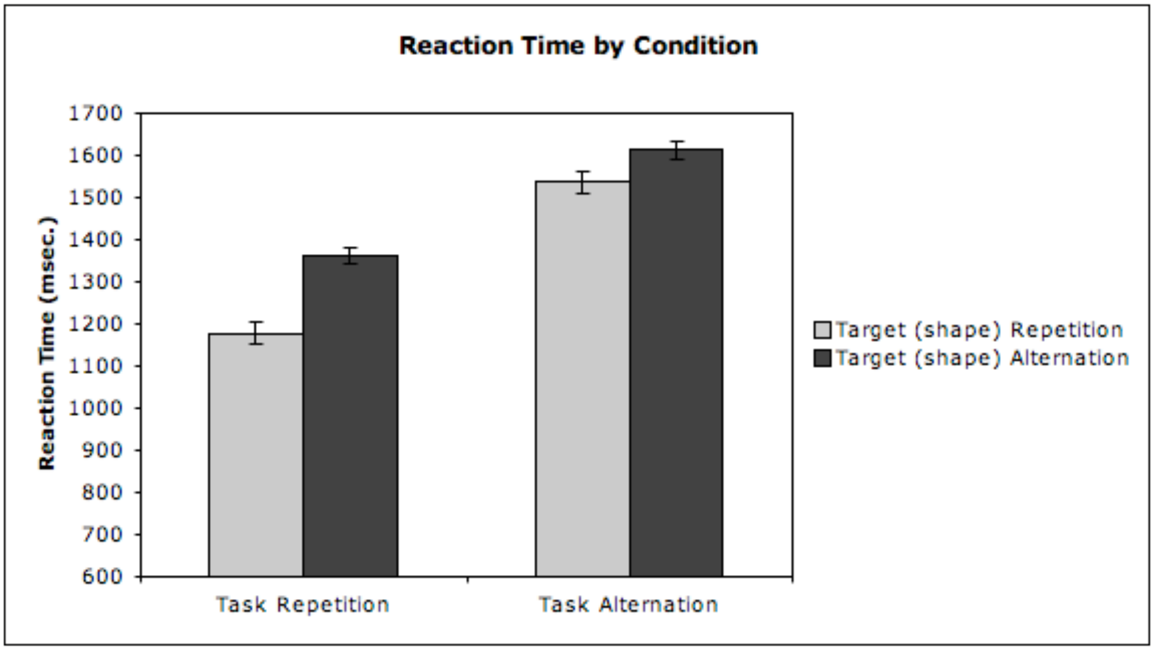

Figure 1b. displays mean reaction time in milliseconds for target shape repetitions and alternations as a function of whether the selection task repeated or alternated from trial *n*-1 to trial *n*.

Table 1. Mean error rates and standard deviations (%) as a function of whether the task repeated or alternated from trial *n*-1 to trial *n* in experiment 1.

	Task Repeat	Task Switch
	M (SD)	M (SD)
Target Repeat	2.38 (1.36)	4.03 (1.90)
Target Switch	3.18 (1.32)	5.00 (1.67)

Response Times. There was a significant main effect of task repetition, with slower responses for task-switch trials (1574 ms) than for task-repeat trials (1270 ms), F (1,19) = 64.62, MSE = 28705.30, $p < .0001$. This result is an example of the well-established task switch cost (Allport, Styles & Hsieh, 1994; Rogers & Monsell, 1995). There was also a significant main effect of target repetition, F (1,19) = 54.94, MSE = 6108.62, $p < .0001$, with faster responses in the target-repeat (1357 ms) than in the target-switch (1487 ms) condition. This result is an example of the well-established PoP effect (Maljkovic & Nakayama, 1994). More important, there was a significant task repetition x target repetition interaction, *F* (1,19) = 12.75, *MSE* 4723.89, *p* = .002. To examine this interaction in further detail, separate analyses of the PoP effect were conducted for the task-repeat and task-switch conditions. These analyses revealed that the PoP effect was significant in both the task-repeat (184 ms), *t* (19) = 8.95, *p* < .0001, and the task-switch (75 ms), *t* (19) = 2.91, *p* = .009, conditions, but was larger in the task repeat condition.

Errors. There was a significant main effect of task repetition, with more errors for task-switch (4.5%) than for task-repeat trials (2.8%), *F* (1, 19) = 12.13, *MSE* = 4.93, *p* = .0025. There was also a significant main effect of target repetition, with significantly more errors for target-switch (4.1%) than for than target-repeat trials (3.2%), *F* (1, 19) = 4.54, *MSE* = 3.48, *p* = .046. The interaction between task repetition and target repetition was not significant. Overall, the pattern of error rates do not favor a speed-accuracy trade off interpretation of our results.

Discussion

The results of Experiment 1 demonstrated that priming of pop-out effects for an odd-shaped target are easily measured with the present task. Furthermore, a clear task-switching cost was present, with participants responding more slowly on task switches relative to task repetitions. Most important, the significantly smaller PoP effects for task switches than for task repetitions demonstrates that PoP for shape-defined targets is sensitive to switches in task. This result is consistent with the idea that PoP effects are modulated by retrieval of memory episodes in which high-level task representations play a role.

Experiment 2

The results of Experiment 1 demonstrated that switching tasks between a 'horizontal/vertical' and 'T or L' judgment significantly reduced PoP effects compared to task repetitions, when the target was defined by shape. This result is in line with a theory in which target shape repetitions were responded to particularly quickly for task repetitions, but not for task alternations, because task alternations require some additional time to resolve the inappropriate task-related processes that are bound together with the appropriate target shape information in the same memory episode

The influence of task-irrelevant features on priming effects in pop-out search has also been offered in support of this episodic retrieval explanation of PoP. Huang, et al. (2004) had subjects perform a pop-out search task for a target defined by size. It was found that when target color repeated from one trial to the next, search times were facilitated, but only when the task-relevant feature also repeated. When the task-relevant feature alternated, irrelevant color repetitions slowed search. These researchers argued that because trial n-1 showed qualitatively different effects on current performance depending on the nature of the current trial, low-level feature priming can not explain the data. In order to examine how a match or mismatch in a target-irrelevant dimension interacts with a task switch, Experiment 2 sought to examine the role of repeating or alternating the task irrelevant color dimension in the present paradigm, while also seeking to replicate the results of Experiment 1.

Method

Participants. The participants were 20 undergraduates at McMaster University with normal or corrected to normal vision. Mean age was 20.3 years (6 male, 14 female). Participants received either course credit or $5 for a half hour of participation.

Procedure. The procedure was identical to that of Experiment 1 with the following exception: the color of the shape elements comprising each stimulus display were either red or green in a random fashion, such that the entire display was either red or green on each trial. Thus, the irrelevant color dimension could either repeat or alternate from trial *n*-1 to trial *n*. An example of the procedure is shown in Figure 2a.

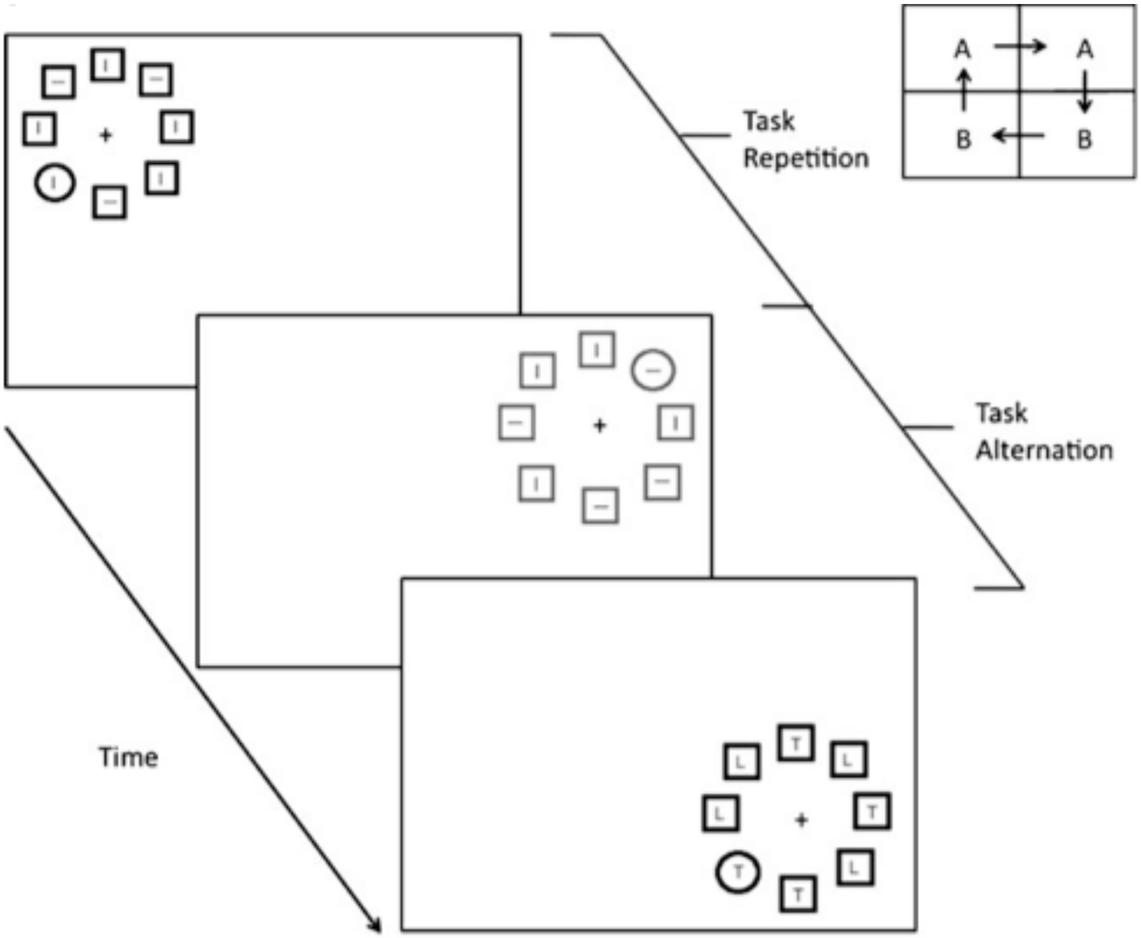

Figure 2a. Displays a sequence of 3 potential trials in which participants locate and respond to the odd-shape in the display – the irrelevant color of the display could repeat or alternate from trial *n*-1 to trial *n*. A task repetition as well as an alternation is depicted. Stimulus displays remained on the screen until a response was made and the next stimulus appeared in the adjacent quadrant after an inter-trial interval of 500ms.

Results

Only the trials on which correct responses were made were submitted to the response time analysis. Trials immediately following an error response were also excluded from analysis. All remaining RTs were submitted to an outlier procedure (see Van Selst & Jolicoeur, 1994). Mean RTs were then computed from the remaining observations. These mean RTs and corresponding errors rates were submitted to a repeated measures analysis of variance that treated target repetition (target-repeat/target-switch) as well as irrelevant color repetition (Color-repeat/ Color-switch) and task repetition (task-repeat/task-switch) as within-subject factors. Means of these mean RTs collapsed across participants, are displayed in Figure 2b and error rates are shown in Table 2.

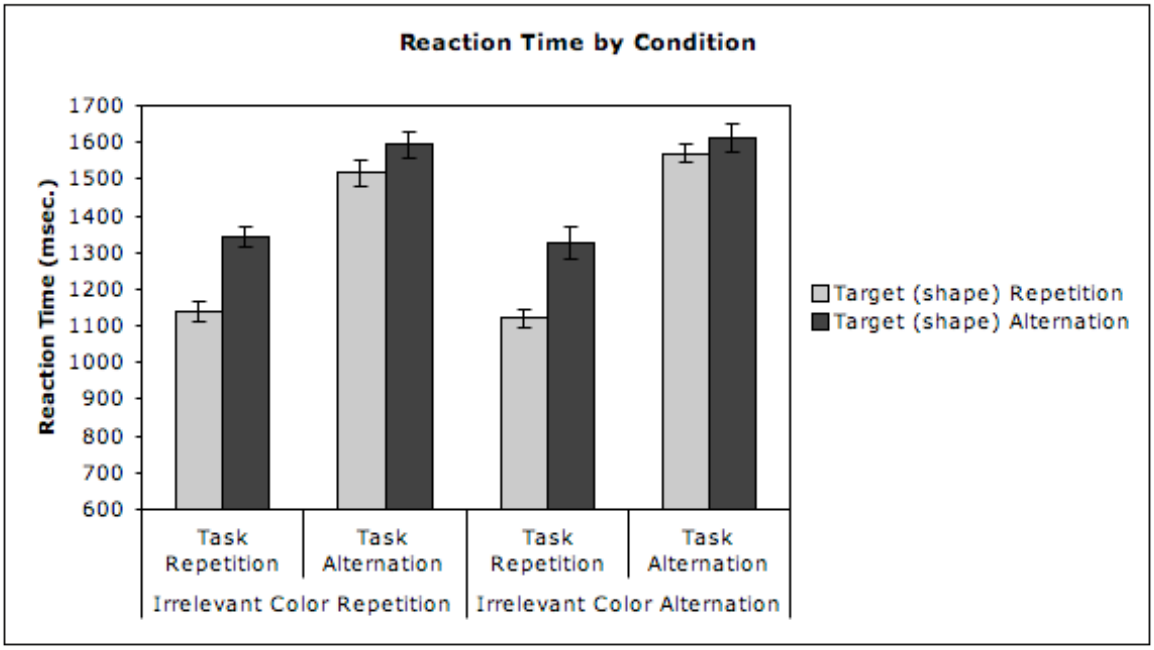

Figure 2b. Displays mean reaction time in milliseconds for target shape repetitions and alternations as a function of whether the irrelevant color repeated or alternated and whether the response selection task repeated or alternated.

Table 2. Mean error rates and standard deviations (%) as a function of whether the irrelevant color repeated or alternated and whether the task repeated or alternated from trial *n*-1 to trial *n* in Experiment 2.

	Irrelevant Color Repetition		Irrelevant Color Alternation	
	Task		Task	
	Repeat	Switch	Repeat	Switch
	M (SD)	M (SD)	M (SD)	M (SD)
Target Repeat	2.28 (2.97)	2.70 (2.23)	2.11 (1.52)	3.90 (2.58)
Target Switch	3.11 (2.99)	4.66 (2.67)	3.56 (3.60)	4.12 (2.43)

Response Times. There was a significant main effect of task repetition, with slower responses for task-switch trials (1573 ms) than for task-repeat trials (1231 ms), *F* (1,19) = 67.61, *MSE* = 69222.4, *p* < .0001. There was also a significant main effect of target repetition, *F* (1,19) = 32.48, *MSE* = 21275.3, *p* < .0001, with faster responses in the target-repeat (1336 ms) than in the target-switch (1467 ms) condition. More important, there was a significant task repetition x target repetition interaction, *F* (1,19) = 10.39, *MSE* = 19966.1, *p* = .0045.

To examine the task repetition x target repetition interaction in further detail, separate analyses of the PoP effect were conducted for the task-repeat and task-switch conditions collapsed across the irrelevant color dimension. These analyses revealed that the PoP effect was significant in the task-repeat (203 ms), *t* (19) = 9.38, *p* < .0001, but not the task-switch (59 ms) condition, demonstrating a significantly larger PoP effect in the task repeat condition.

There were no significant effects involving the irrelevant color repetition variable.

Errors. There was a marginally significant main effect of task repetition, with more errors for task-switch (3.8%) than for task-repeat trials (2.8%), *F* (1, 19) = 3.6, *MSE* = 12.84, *p* = .073. There was also a significant main effect of target repetition, with significantly more errors for target-switch (3.9%) than target-repeat trials (2.8%), *F* (1, 19) = 7.59, *MSE* = 6.56, *p* = .0126. The interaction between task repetition and target repetition was not significant. Overall, the pattern of errors did not favor a speed-accuracy trade-off interpretation of the RT patterns reported above.

Discussion

One of the purposes of Experiment 2 was to provide a replication of the primary result of Experiment 1, that a shift in the response selection task would modulate PoP effects relative to a task repetition. The results once again show that overall, PoP was significantly smaller when the response selection task on the previous trial was different than on the current trial. This result provides further support for the hypothesis that episodic retrieval can modulate PoP effects.

A second purpose of Experiment 2 was to extend the findings of Experiment 1 by investigating the role of a task-irrelevant color dimension on inter-trial priming in pop-out search. There was no evidence in the current experiment that irrelevant color repetition from trial *n*-1 to trial *n* modulated PoP effects, a result that differs somewhat from that reported by Huang et al. (2004), who did report an influence of repetition of an irrelevant color dimension on PoP effects. Although we are uncertain as to why the results from these two studies differ in this respect, there were some methodological differences between their study and ours that may account for the different results. While target color varied randomly (either red or green) on each trial in our experiment, both the target and distracters were all assigned the same color value on a given trial. In other words, all elements in the display were either red or green. In Huang et al. (2004), each item in the display was assigned a random color value on each trial (black or white), such that on each trial there were both black and white elements in the display. Although it is unclear exactly why such a procedural difference would yield different results, it may be that variation of color within a display leads to greater selective attention to the color dimension despite its irrelevance to the task, and in turn attention to the irrelevant color dimension may be critical to observe the result reported by Huang et al. (2004). Put differently, it could be the case that when a target relevant or irrelevant feature varies within a display (e.g. Left/right, big/small, black/white) that feature is likely to attract sufficient attention to be encoded in the resulting memory. Although mere speculation at present, this proposal could be tested empirically in future work. In any case, sensitivity of the PoP effect to a switch in task, which was observed here, is consistent with an episodic interpretation of the PoP effect.

Experiment 3

In the experiments reported so far, the task of the participants was to locate a singleton target shape on each trial. In the original demonstration of PoP by Maljkovic and Nakayama (1994), participants searched for a singleton color target on each trial. The purpose of the present experiment was to examine whether the task switching influence on PoP effects observed in Experiments 1 and 2 for shape singleton targets would also occur for color singleton targets.

Method

Participants. The participants were 20 undergraduates at McMaster University with normal or corrected to normal vision. Mean age was 19.5 years (9 male, 11 female). Participants received either course credit or $5 for a half hour of participation.

Procedure. The procedure was identical to that of Experiment 2 with the following exception: participants searched for an odd colored item in each display instead of an odd-shaped item. The irrelevant stimulus dimension in this experiment was shape, which could repeat or alternate from trial to trial in a random manner. Therefore, each stimulus display consisted of either 8 squares or 8 circles, and the target was either red or green. As before, subjects performed a ‘horizontal/vertical’ or ‘T or L’ judgment on the line or letter contained within the singleton target. An example of the procedure is shown in Figure 3a.

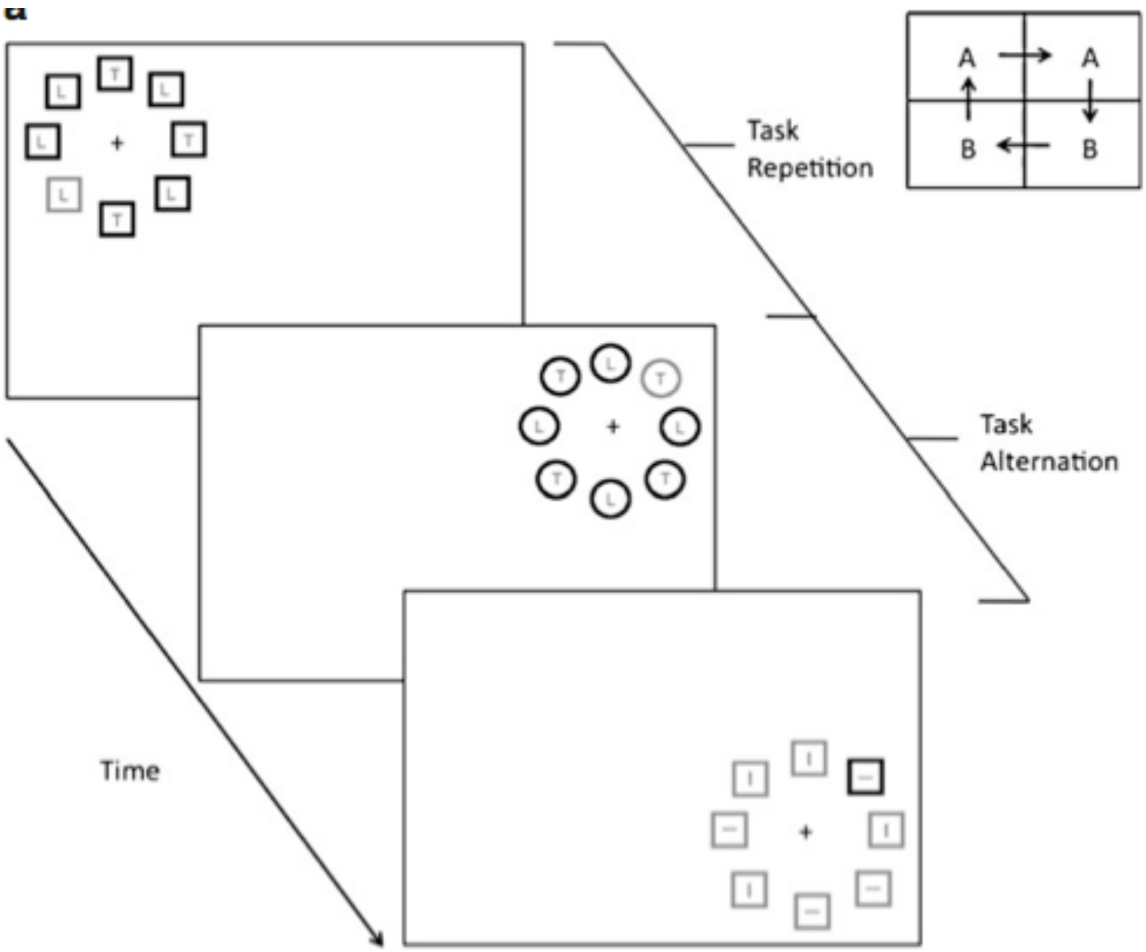

Figure 3a. Displays a sequence of 3 potential trials in which participants locate and respond to the odd-colored item in the display – the irrelevant shape of the stimulus elements could either repeat or alternate from trial *n*-1 to trial *n*. A task repetition as well as an alternation is depicted. Stimulus displays remained on the screen until a response was made and the next stimulus appeared in the adjacent quadrant after an inter-trial interval of 500ms.

Results

Only the trials on which correct responses were made were submitted to the response time analysis. Trials immediately following an error response were also excluded from analysis. All remaining RTs were submitted to an outlier procedure (see

Van Selst & Jolicoeur, 1994). Mean RTs were then computed from the remaining observations. These mean RTs and corresponding error rates were submitted to a repeated measures analysis of variance that treated target repetition (target-repeat/target-switch) as well as irrelevant shape repetition (Shape-repeat/Shape-switch) and task repetition (task-repeat/task-switch) as within-subject factors. Means of these mean RTs, collapsed across participants, are displayed in Figure 3b and error rates are shown in Table 3.

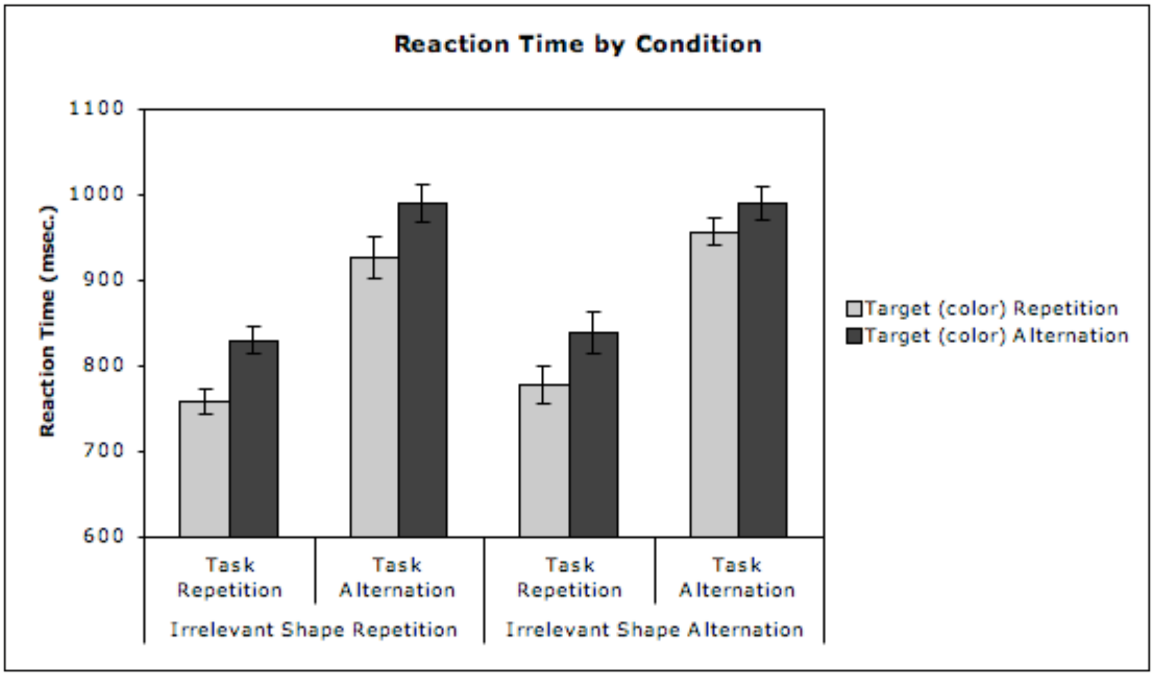

Figure 3b. Displays mean reaction time in milliseconds for target color repetitions and alternations as a function of whether the irrelevant shape repeated or alternated and whether the response selection task repeated or alternated.

Table 3. Mean error rates and standard deviations (%) as a function of whether the irrelevant shape repeated or alternated and whether the task repeated or alternated from trial *n*-1 to trial *n* in Experiment 3.

	Irrelevant Shape Repetition		Irrelevant Shape Alternation	
	Task		Task	
	Repeat	Switch	Repeat	Switch
	M (SD)	M (SD)	M (SD)	M (SD)
Target Repeat	4.13 (4.75)	7.56 (4.10)	4.38 (2.72)	7.57 (4.08)
Target Switch	4.39 (3.83)	8.60 (3.44)	4.85 (3.17)	9.27 (5.81)

Response Times. There was a significant main effect of task repetition, with slower responses for task-switch trials (966 ms) than for task-repeat trials (801 ms), *F* (1,19) = 29.26, *MSE* = 36904.00, *p* < .0001. There was also a significant main effect of target repetition, *F* (1,19) = 11.82, *MSE* = 10852.30, *p* = .0028, with faster responses in the target-repeat (855 ms) than in the target-switch (912 ms) condition. Unlike the previous two experiments however, there was no significant task repetition x target repetition interaction, *F*<1. Irrelevant shape repetition did not affect performance either in isolation or in combination with any of the other factors.

Errors. There was a significant main effect of task repetition, with more errors for task-switch (8.3%) than for task-repeat trials (4.4%), *F* (1, 19) = 10.77, *MSE* = 53.83, *p* = .0039. There were no other significant effects observed in the pattern of error rates.

Discussion

The primary goal of Experiment 3 was to test whether a task switch mediates PoP measured using color singleton targets. Unlike Experiments 1 and 2 when targets were shape singletons, there was no evidence that a switch in task affected PoP effects with color singletons, either when the irrelevant shape dimension repeated or when it switched. Taken literally, the results of Experiments 1-3 might be taken to imply that task switches modulate PoP effects for shape singleton targets but not for color singleton targets, although this is little more than a description of the results. Why shape singletons would have a special status with respect to task switch influences on PoP effects is simply not clear.

An alternative approach to interpreting the results of Experiments 1-3 is to assume that task switching can modulate PoP effects for both shape and color singletons, and for any type of singleton for that matter, but that there are some limiting conditions for observing such an effect. For reasons not yet clear, it may have been the case that the color singleton search task in Experiment 3 approached such a limiting condition whereas the shape singleton search task in Experiments 1 and 2 was well within the range of conditions under which task switching impacts PoP effects. For example, it could be that singleton salience modulates whether task switching alters PoP effects, with task switching not affecting PoP effects for particularly salient singletons, such as color-defined targets. Indeed, responses in Experiment 3 were approximately 500 ms faster than those in Experiments 1 and 2, consistent with the idea that the color singleton targets in Experiment 3 were more salient relative to the distracters than were the shape singleton targets in Experiments 1 and 2. We pursued this issue in Experiment 4 by directly varying relative salience of targets with respect to distracters in a color singleton search task.

Experiment 4

In this experiment we examined further whether task switching modulates PoP effects for color singleton targets, and in particular whether such an effect might be modulated by singleton salience. To this end, salience of the color singleton relative to the distracters was manipulated between blocks in the present experiment.

A secondary purpose of Experiment 4 was to address a potential alternative account of the results of Experiments 1 and 2. In particular, note that in the procedure used to this point, participants responded to target stimuli that appeared within the perimeter of target objects, and these target stimuli differed across the two tasks. In one task the target stimuli were vertical and horizontal lines, whereas in the other task the target stimuli were the letters 'T' and 'L'. Consequently, a possible criticism of the conclusion that PoP effects varied as a function of task switches in Experiments 1 and 2 is that perceptual mismatches between the target stimuli for the two tasks rather than the task switch itself may have been responsible for the effects observed. To address this issue, we used identical target stimuli for the two tasks in Experiment 4. An additional criticism that might be leveled against the results of Experiments 1 and 2 is that responses could require participants to first locate the target object and then to re-focus attention to the target stimulus within the target object. In contrast, the procedure often used to measure PoP effects (e.g., Bravo & Nakayama, 1992; Maljkovic & Nakayama, 1994) requires participants to respond to a property of the target object (e.g., which side of a shape is missing a corner), rather than to a target stimulus within the target object. To address this issue, we had participants respond to a property of the target object in Experiment 4, with participants indicating whether a gap in the perimeter of a target object was on the left or right for one task, or on the top or bottom for the other task.

Method

Participants. The participants were 32 undergraduates (4 male, 28 female) at McMaster University with normal or corrected to normal vision. Mean age was 18.9 years. Participants received either course credit or $5 for a half hour of participation.

Procedure. Participants were seated in front of a computer screen and were instructed that upon stimulus onset they were to locate the odd-colored item in the eight-element circular display, and make either a top/bottom or left/right decision about the gap in the odd colored item, depending on the quadrant of the screen in which the stimulus display appeared. An AABB task switching procedure was used, in which the task to be performed was dictated by where on the screen the search array appeared (Rogers & Monsell, 1995). Half of the participants performed a top/bottom judgment when the displays appeared in the top two quadrants of the screen and a left/right discrimination when the displays appeared in the bottom two quadrants of the display, and this assignment of tasks to position was reversed for the other half of the participants. Once a stimulus was responded to, the next search array appeared after a 500 millisecond blank interval, and in the location adjacent to the previous array in a clock-wise direction. As such, the position of the next display as well as which task was to be performed was perfectly predictable. The responses for both tasks were mapped to the same keys such that a ‘left’ or ‘top’ response required pressing the ‘Z’ key and a ‘right’ or ‘bottom’ response required pressing the ‘/’ key. Subjects were explicitly told about the predictable task repetitions and alternations and were asked to be as fast and accurate as possible when doing both tasks.

The experiment was divided into two blocks of trials. For one block, the relative salience of the target and distracters was similar to that in Experiment 3, with green singleton targets surrounded by red distracters or vice versa. For the other block, the relative salience of target and distracters was manipulated such that a green target would be surrounded by turquoise distracters or vice versa. The order of the two blocks was randomly counterbalanced between participants. The first 12 trials of each block were practice trials to familiarize subjects with the tasks and stimulus-response mappings. Response times as well as errors were recorded for an additional 388 trials, for a total of 400 trials per block. Upon completion, participants were debriefed on the nature of the task and given the opportunity to ask questions. An example of the procedure is shown in Figure 4a.

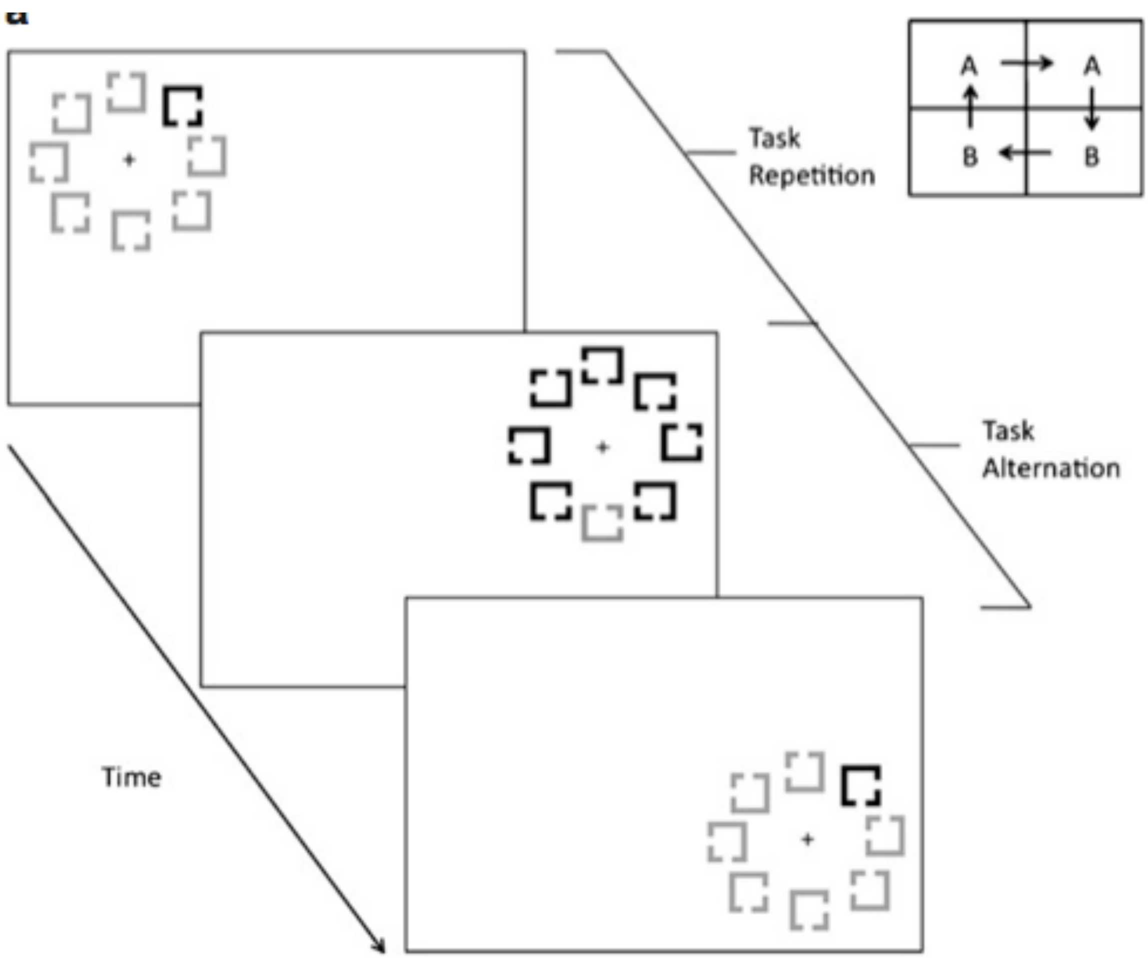

Figure 4a. Displays a sequence of 3 potential trials in which participants locate and respond to the odd-colored item in the display – target and distracter salience was manipulated between conditions. A task repetition as well as an alternation is depicted. Stimulus displays remained on the screen until a response was made and the next stimulus appeared in the adjacent quadrant after an inter-trial interval of 500ms.

Stimuli and Apparatus. Subjects were seated approximately 50 cm away from a computer screen with their index fingers poised over each of the two response keys. Each stimulus display contained eight squares with a gap in either the top or the bottom and in either the left or the right side. Each shape subtended a visual angle of about 1.1

degrees and the entire stimulus display subtended a visual angle of about 6.5 degrees, with a fixation cross that subtended about 0.6 degrees. Displays appeared in one of four quadrants of the computer screen (although quadrants were not visibly marked on the screen) and remained until response, which was initiated via a key press. The responses 'left' and 'top' were mapped to the 'Z' key and the responses 'right' and 'bottom' were mapped to the '/' key on the keyboard. Stimuli were presented on a 15-inch Sony CRT screen. For the high salience condition, target and distracter elements were red and green whereas in the low salience condition, target and distracter elements were turquoise and green. Display elements were created and presented using Presentation Software.

Results

Only the trials on which correct responses were made were submitted to the response time analysis. Trials immediately following an error response were also excluded from analysis. All remaining RTs were submitted to an outlier procedure (see Van Selst & Jolicoeur, 1994). Mean RTs were then computed from the remaining observations. These mean RTs and corresponding errors rates were submitted to a repeated measures analysis of variance that treated target repetition (target-repeat/target-switch), task repetition (task-repeat/task-switch) and block (high salience/low salience) as within-subject factors; block order was treated as a between subjects factor. Mean response times collapsed across participants are shown in Figure 4b and error rates are shown in Table 4.

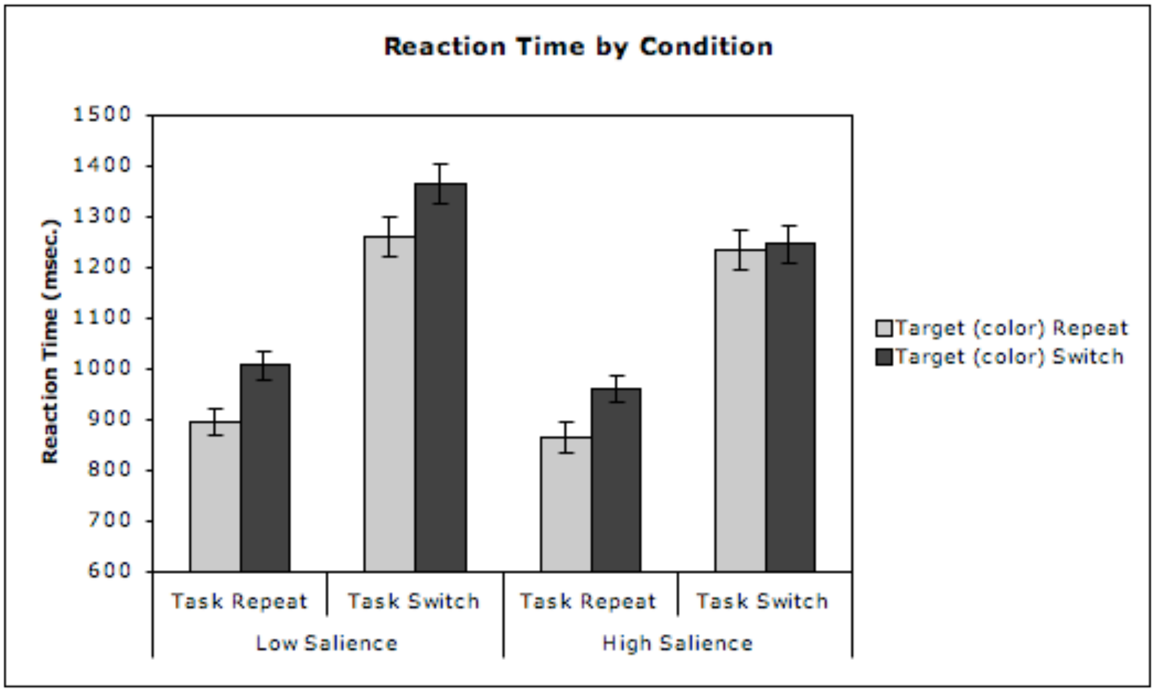

Figure 4b. Displays mean reaction time in milliseconds for target color repetitions and alternations as a function of whether the selection task repeated or alternated, from trial *n*-1 to trial *n*, and whether the relative salience of target and distracters was high or low.

Table 4. Mean error rates and standard deviations (%) for the high and low-salience conditions as a function of whether the task repeated or alternated from trial *n*-1 to trial *n* in Experiment 4.

	Low-Salience		High-Salience	
	Task		Task	
	Repeat	Switch	Repeat	Switch
	M (SD)	M (SD)	M (SD)	M (SD)
Target Repeat	2.07 (3.05)	5.20 (3.01)	2.99 (3.66)	6.38 (4.11)
Target Switch	2.91 (3.74)	5.19 (4.21)	3.25 (3.05)	5.56 (3.93)

Response Times. There was a main effect of salience, with RTs being faster in the high salience condition (1076 ms) than the low-salience condition (1132 ms), *F* (1,30) = 4.43, *p* = .0438, *MSE* = 45389. There was a significant main effect of task repetition, with slower responses for task-switch trials (1277 ms) than for task-repeat trials (932 ms), *F* (1,30) = 190, *MSE* = 38755.70, *p* < .0001. There was also a significant main effect of target repetition, *F* (1,30) = 42.47, *MSE* = 9615.96, *p* < .0001, with faster responses in the target-repeat (1063 ms) than in the target-switch (1145 ms) condition.

The 3-way interaction between target, task, and salience, was significant, *F* (1,30) = 5.25, *MSE* = 4333.70, *p* = .0269. To interpret this interaction, separate 2 (target repeat/switch) x 2 (task repeat/switch) ANOVAs were conducted to assess how PoP was affected by a task switch in the high and low-salience conditions. For the low-salience condition, there was no significant 2-way interaction between task and target, *F* < 1. PoP effects therefore, were not affected by a switch in task in this condition. For the high-salience condition, there was a significant 2-way interaction between task and target, *F* (1,31) = 9.65, *MSE* = 5950.06, *p* = .004. Thus, the significant 3-way interaction is being driven by a significant modulation of priming of pop-out across task in the high-salience, but not the low-salience condition. To confirm this interpretation, separate analyses of the PoP effect were conducted for the task-repeat and task-switch conditions for the high salience condition. These analyses revealed that the PoP effect was significant in the task-repeat condition (95 ms), *t* (31) = 5.12, *p* < .0001, but not the task-switch (11 ms) condition.

Errors. The only significant effect in this analysis was the main effect of task repetition, with more errors committed for task-switch trials (5.6 %) than for task-repeat trials (2.8 %), *F* (1,31) = 52.87, *MSE* = 9.15, *p* < .0001.

Discussion

The results of Experiment 4 demonstrate clearly that PoP effects for color singleton targets can be modulated by task switches. In the high-salience condition, the PoP effect was larger for task repeats than for task alternations. As such, it seems clear that the task switch modulation of the PoP effect observed in Experiments 1 and 2 is not idiosyncratic to shape singleton targets. At the same time, the fact that this effect occurred for the high-salience condition and not for the low-salience condition undermines any simple notion that the different results for shape and color singleton targets across Experiments 1-3 was a result of salience differences between the shape and color singleton targets in these experiments. Indeed, the high salience condition of the present experiment used color pop-out targets that were very similar to those used in Experiment 3, and yet task switches modulated PoP effects here but not in Experiment 3. These results highlight the fact that factors other than singleton salience must dictate the extent to which task switching modulates PoP effects. This issue is addressed in more detail in the General Discussion.

An additional implication of the results of this experiment is that task switch modulations of PoP effects do not require perceptual mismatches between the targets of the two tasks. Whereas in Experiments 1-3 participants responded to different target stimuli in the two tasks, the target stimuli in the two tasks were identical in the present experiment. In addition, the task switch modulation of color PoP observed in the high-salience condition here occurred in a task much like that used originally by Bravo and Nakayama (see also Maljkovic & Nakayama, 1994), in that participants responded to a property of the target object itself rather than to a target stimulus that appeared within the target object.

A final concern that might be expressed about this experiment is that we have no basis for being sure that the targets in the low salience condition truly allowed pop-out search, as the target and distracter colors were quite similar in this condition. Our response to this concern is that, indeed, the low salience targets may not have popped out to the same extent as the high salience targets (although note that the mean RTs differed by only about 50 ms across these two conditions), but the key result here is the result in the high salience condition. In particular, for high salience singleton color targets, a switch in task did modulate the PoP effect, a result that is difficult to accommodate without reference to the involvement of higher order task level aspects of representation.

General Discussion

The primary goal of the experiments reported here was to examine whether a higher order switch in selection task from trial *n*-1 to trial *n* would affect the priming of pop-out effect in visual search. Experiments 1 and 2 demonstrated that a switch in selection task significantly reduced the magnitude of the PoP effect, when the target was defined as the odd-shaped item in the display. Experiment 3 failed to show such modulation when the target was defined as the odd-colored item in the display. Experiment 4 demonstrated that PoP for color can indeed be modulated by a switch in selection task from trial *n*-1 to *n*, in this case when the relative salience of targets with respect to distracters was high. Although the role of stimulus salience in this effect is unclear and will be an issue for future study, the primary contribution of the present work is to show that the memory representations that drive PoP can include higher order information as well as low-level perceptual information.

Maljkovic and Nakayama's initial (1994; 1996; 2000; see also, Bravo & Nakayama, 1992) explanation of PoP proposed that such effects result from the short-term persistence of a memory representation involving the target-defining feature. Clearly, the results of the present experiments suggest that more than the target-defining feature is involved in the memory representation that supports PoP effects. Although other studies have also implicated memory representations involving more than just target-defining information (Huang, et al., 2004; Lee et al., 2009), to our knowledge ours is the first study to implicate higher-level task-related processes in the memory representations that support PoP.

Lee et al. (2009) have forwarded an account of PoP that describes how multiple pieces of information can be represented from one trial to the next, and subsequently affect performance. These researchers have argued that independent activation/suppression of 'feature weights' from one trial to the next are what create memory representations that persist across trials. In this view, perceptual properties of a target stimulus are independently represented in memory for a short time. The way in which these weights are argued to be modulated from one trial to the next is via cognitive control operations that activate or suppress certain features of the stimulus display in accord with the demands of the task (goals of the observer). Much like the memory trace posited by Maljkovic and Nakayama (1994), these representations of 'feature weights' persist for a short time, allowing search time savings if a subsequent trial requires the same assignment of feature weights, or costs if different or opposite weights are required.

A central tenet of feature modulation theory is that different features are activated and suppressed in an independent manner. That is, a memory trace could include the activation of one feature, say, 'red', and the activation of a separate feature, say, 'large', that would provide search time savings if the next trial included target features that were either 'red' or 'large'. Even more savings in search times would be observed if the next trial included target features that were both 'red' and 'large', and thus additivity of these factors from trial n-1 to trial n would be a clear demonstration of the independence of the feature representations of 'red' and 'large'. Furthermore, this theoretical interpretation of PoP posits that only low-level, or perceptual information gets represented from one trial to the next. That is, there is no obvious way in which feature gains can be adjusted for non-perceptual information. In summary, the feature gain modulation account of PoP assumes independent representation of low-level perceptual attributes, the memory of which persists from one trial to the next.

An alternative account of PoP that also allows for a memory influence from more than one stimulus dimension assumes that multiple stimulus dimensions are bound together in memory rather than represented independently. Huang et al. (2004) argued specifically that such bound representations, referred to as memory episodes, might underlie PoP effects in singleton search. Like feature gain modulation theory, an episodic theory predicts that performance on trial *n* should be affected by whether or not trial n shares perceptual properties with trial *n*-1. Unlike feature gain modulation theory, an episodic theory predicts interactions involving repetition/alternation of separate features. For example, repeating one feature of a stimulus, but alternating another, might well slow search time relative to a condition in which both stimulus features alternate (see Hommel, 1998). Another theoretical distinction between feature gain modulation and episodic theories is that episodic representations can in principle include higher level (non-perceptual) information as well as low level (perceptual) information, whereas it is not obvious how task-related information can be incorporated into a feature gain modulation account of PoP. With respect to the results of the present experiments, target and task variables clearly can affect performance in a non-additive manner; that is, in at least some contexts task and target repetition interact to produce significantly smaller PoP effects for task switches than for task repetitions. Such results appear easier to accommodate within an episodic retrieval framework than within a feature gain modulation framework for explaining PoP.

Lee et al. (2009) did offer a way in which feature modulation theory can account for non-additive effects of target relevant and irrelevant information in pop-out search. In particular, they stated that the results of Huang et al. (2004) can be accounted for within a feature modulation framework if we assume that the features that represent an object are bound together in memory, with independent weights set for each feature. To the extent that the encoded 'object' changes from one trial to the next, performance would be expected to suffer.

Put in these terms, the feature modulation account of PoP effects has much in common with other theories that have invoked the integration of features into object representations to explain inter-trial priming effects. Kahneman, Treisman and Gibbs (1992) showed that the ability of participants to respond to the second presentation of a letter was significantly diminished when that letter appeared within a different object from one exposure to the next. They argued that features of objects are bound together in memory, creating what they referred to as 'object files', which are created and retrieved on each trial. The only real distinction to be made between the explanation of Lee et al. (2009) with regards to bound objects and the concept of object files as offered by Kahneman et al. (1992) is that Kahneman et al. went to some lengths to demonstrate that object files can be retrieved and updated upon onset of a subsequent stimulus display, rather than simply persisting passively for some limited amount of time.

The notion of bound representations of feature weights, or of object files, holds a lot of explanatory power in accounting for interactions among low-level perceptual attributes in a pop-out search task. However, the present results demonstrate an interaction involving both low-level stimulus attributes and higher-level, non-perceptual information. With this in mind, it is noteworthy that Hommel (1998) extended the concept of object files to include the goals and the behavior of participants. By this view, perceptual as well as non-perceptual attributes of a given trial are bound up in a single representation that Hommel referred to as an 'event file'. This extended episodic framework allows for, and indeed predicts, that switching task in the present study should reduce the facilitation that occurs for target repetitions from trial *n*-1 to *n*.

Although it is clear that we have found conditions under which higher-level influences can be observed on the PoP effect, we also have discovered conditions under which no such influences can be observed. For example PoP was modulated by task switches for the high-salience condition of Experiment 4, but not in Experiment 3 when the same target and distracter colors were used, and only for targets defined by shape across Experiments 1-3. It is therefore clear that there are limiting conditions for observing interactions among higher-level and lower-level stimulus attributes in a singleton search task. While the pursuit of these limiting conditions is an issue for further study, two observations can be made here. First, methodological changes between Experiments 1-3 and Experiment 4 make it difficult to postulate a single process or stimulus attribute that can adequately account for the discrepancies in our results. Specifically, recall that in Experiments 1-3, participants had to re-focus attention within the target object once it was localized in order to respond, whereas in Experiment 4, no such re-focusing was required. Second, it is clear that neither the relative salience of targets with respect to distracters nor the target-defining feature (shape/color) alone can delineate these limiting conditions.

In light of these observations, a full account of the results reported here might ultimately have to take into account strategic influences on task-related processes. In particular, it seems possible that participants may approach the search task in functionally different ways in different contexts. For example, on a trial that involves a task switch one could first engage the appropriate task set for that trial and then localize the target, or one could localize the target and then engage the appropriate task set. From an episodic perspective, the cues that drive retrieval of prior episodes would be entirely different in these two cases and therefore, for example, the former strategy might be less likely to demonstrate a PoP effect in the context of a task switch. Admittedly, such an account is speculative, as it is not yet clear which particular combinations of task variables would lead one strategy to dominate over the other, but it does offer a starting point for further empirical work.

In summary, there exists debate in the literature with respect to the nature of the memory mechanism underlying the priming of pop-out effect. Some researchers argue that the existing data is best explained via reference to independent activation and suppression of feature weights that persist from one trial to the next (Lee et al., 2009). Others interpret the data as being best explained within an episodic retrieval framework, in which perceptual and non-perceptual information is represented in a non-independent manner from one trial to the next (Huang et al., 2004). The results of the present study demonstrate that under some conditions, the effect of higher level, non-perceptual information can affect the PoP effect. Moreover, this non-perceptual information interacts with low-level target-defining information, suggesting that these attributes are bound together in a non-independent manner in memory. Although it is clear that much more work must be done to better elucidate the conditions under which higher-level influences on PoP can be observed, making use of episodic retrieval theories to make predictions about the nature of PoP effects seems a productive endeavor in light of the present work.

CHAPTER 3: The Time Course of Priming of Pop-Out

PREFACE

Chapter 2 provided initial support for an episodic retrieval explanation of the priming of pop-out effect by demonstrating that non-perceptual, task-related information has a significant impact on the magnitude of the PoP effect from one trial to the next. A key piece of evidence against episodic retrieval explanations of PoP (that is, stable, long-term episodic representations) is that PoP is very short-term in nature. Yet, the dependence of the PoP effect on time has been the target of surprisingly little research to date. The research in Chapter 3, therefore, examines directly the time course across which PoP effects can be measured. The results of Experiment 1 show that PoP effects can be measured empirically with a 16 second interval between the current and previous trials, and that the 'decay' of the PoP effect is fit well by a power-law function that predicts PoP effects far beyond the conventional limits of short-term memory. Although this result converges with the results of Chapter 2 in implicating a role for episodic memory in PoP, the results of Experiment 2 in the present chapter suggest that PoP is not sensitive to proactive interference from the trial preceding the current trial. Together, the results of these experiments point to potential long-term memory influences on PoP effects, but not to influences that are subject to proactive interference.

Abstract

The priming of pop-out (PoP) effect in efficient visual search has been argued to reflect the persistence of a short-term, transient, memory trace (Malkjovic & Nakayama, 1994; 2000). As a result of the fact that PoP can be observed for about 5-8 subsequent trials at the most, it has been argued that PoP is driven by target activation and distracter

inhibition processes that decay rapidly across time. However, this conclusion has been based on prior work in which the passage of time between a search trial and a given prior influencing trial has been confounded by the presence of intervening search trials. In the present experiments, we measured directly the effect of time alone on the magnitude of priming effects in a color pop-out search task by randomly varying the response-to-stimulus interval on a trial-by-trial basis. The results of Experiment 1 demonstrate that PoP diminishes rapidly within the first second, post-response, but then diminishes much more slowly, following a power-law function. We argue that previous methods for calculating the 'duration' of PoP are insufficient, and that the memory underlying this effect could conceivably affect performance well beyond the limits of short-term memory. At the same time, the results of Experiment 2 suggest that PoP is not sensitive to proactive interference from the trial preceding the prime. Implications for this finding with respect to leading theoretical accounts of PoP are then discussed.

The role of memory in human performance is an important issue in cognitive psychology. Research in this area aims to understand how prior experiences guide current behaviors, outside of deliberate attempts to remember. This issue is particularly salient in the domain of singleton, or pop-out search, in which participants are asked to locate an odd target amongst homogeneous distracters. Although there is wide agreement that memory does indeed guide performance in singleton search (as evidenced through robust inter-trial priming effects), the nature of the underlying memory representation has been an issue of much debate. Some researchers have argued that retrieval of episodic memories can explain the existing data (Hillstrom, 2000; Huang, Holcombe & Pashler, 2004; Thomson & Milliken, 2011), while others have argued that such effects are best interpreted by reference to feature-specific and transient memory traces (Malkjovic & Nakayama, 1994; Lee, Mozer & Vecera, 2009).

Malkjovic and Nakayama (1994) had participants locate an odd-colored shape amongst two homogeneous distracters and report which side of the target was truncated. Critically, search times were faster when the color of the target on a given trial was the same as the color of the target on the previous trial, relative to when target colors were different. This effect, termed priming of pop-out (PoP), demonstrated that previous experience can guide search performance by modulating the degree to which targets capture attention in space. PoP was originally thought to reflect the operation of a memory trace that stores target-defining feature information only (Malkjovic & Nakayama, 1994; 1996; 2000). These memories were argued to operate at a so-called 'pre-attentive' stage in search (see Treisman & Gelade, 1980), in which experience serves to update and refine a salience-map that guides attention to salient objects in space.

The idea that PoP is driven by memory traces that encode target-defining feature information only has since been modified, as numerous studies have shown that task-irrelevant stimulus attributes can also affect inter-trial priming effects (Olivers & Humphreys, 2003; Huang et al., 2004; Kristjansson, 2006; McBride, Leanords & Gilchrest, 2008). As a result, mechanisms that take into account both target-defining information, as well as other low-level information, have been invoked to explain the underlying mechanism of PoP. These theories are sometimes referred to as activation/suppression accounts (Lee, et al., 2009) or early 'attentional' accounts (Lamy, Yashar & Ruderman, 2010). In general, all such theories posit independent potentiation of feature weights related to low-level perceptual information on one trial that can be measured on a subsequent trial, although some theories simply make reference to low-level feature priming (Wolfe, Butcher, Lee & Hyle, 2003; Olivers & Humphreys, 2003; Wolfe, 2003), while others posit trial-to-trial adjustments in cognitive control settings (Lee et al., 2009). In the remainder of this article we refer to these ideas collectively as activation/suppression accounts of PoP.

An alternative theoretical account of recent findings in the PoP literature makes reference to the role of episodic representations. This general framework has been applied successfully to a host of other priming effects in performance tasks such as negative priming (Neill, Valdes, Terry & Gorfein, 1992), conflict adaptation (Spape & Hommel, 2008), and inhibition of return (Tipper, Grison & Kessler, 2003; Wilson, Castel & Pratt, 2006). It assumes that processing episodes that bind together information from attended stimulus dimensions are created and retrieved on each trial (see Logan, 1988; Hommel, 1998). Unlike feature priming accounts, episodic retrieval accounts of PoP effects predict that more than low-level perceptual information holds the potential to affect performance and that retrieval of memory representations should be subject to match or mismatch in task-irrelevant contextual and perceptual dimensions, in line with the transfer appropriate processing principle (Morris, Bransford & Franks, 1977). Although this episodic framework has garnered empirical support from recent work (Hillstrom, 2000; Huang et al., 2004; Thomson & Milliken, 2011), several of its predictions have yet to be tested.

A clear prediction of activation/suppression theories is that the perceptual memory traces underlying the PoP effect ought to decay passively over time and that after some given amount of time, priming effects should not be observed. Prior studies have measured PoP effects that last for up to 5-8 subsequent trials (as measured on a current trial as a function of some prior trial, e.g. *n*-8, here after referred to as the influencing trial) (Malkjovic & Nakayama, 1994). On the basis of these results, the 'duration' of the memory trace underlying PoP has been argued to be approximately 30 seconds. This number reflects the sum of the response-to-stimulus inter-trial intervals (RSIs) between search arrays (2,500 ms x 8), plus the response times for the 5-8 influencing trials on which PoP could be measured. Hillstrom, however, used 800 ms RSIs and found PoP for color could be measured on trial *n* only back as far as trial *n*-3. Using the formula of Malkjovic and Nakayama therefore, the 'duration' of PoP in the study of Hillstrom (2000; Experiment 1) would be approximated at around 4 seconds. Given these vastly different estimates of the duration of PoP effects, it seems likely that the 'duration' of the underlying memory trace cannot be computed as the sum of the response times and RSIs across which a PoP effects can be measured. Moreover, measuring the ‘decay’ associated with target feature activation is difficult when the time between the influencing trial and the current trial is confounded with intervening items (as has been the case in all prior studies on PoP). Yet there are no published studies to our knowledge that include a direct manipulation of RSI in a standard color pop-out task. The goal of Experiment 1, therefore, was to assess PoP effects as a function of time between the preceding and current trial, without the confound of intervening experiences.

Although both the activation/suppression and episodic retrieval accounts of PoP predict that as RSI increases, PoP ought to diminish, the rationale for these predictions are very different for the two theories. An activation/suppression account predicts that feature gains set on trial *n*-1 begin to decay back to some baseline level post-response, and so as time increases, the potentiation of such gains diminishes. As a consequence, PoP effects should be eradicated by time alone, when sufficient time has elapsed for feature gain activation/suppression states to return to baseline. In contrast, episodic retrieval theories posit that as the time between a prior processing episode and current perception increases, shifts in context that invariably occur with time will decrease the likelihood of retrieval of the prior processing episode. In turn, with a decreased likelihood of retrieval of the prime episode, the size of the PoP effect ought to decrease as time passes between trial *n*-1 and trial *n*. Unlike activation/suppression theories, there is nothing inherent to an episodic retrieval account that requires the PoP effect to be eliminated by time alone. Indeed, given that episodic retrieval could well be cued by re-instatement of context, a PoP effect could in principle be observed with even a substantial interval between trial *n*-1 and trial *n*. In any case, the duration after which PoP can still be measured, when time alone is manipulated, is an open issue. The purpose of Experiment 1 was to examine in detail the relation between RSI and PoP.

Another way in which activation/suppression accounts and episodic retrieval accounts differ in terms of the predicted effects of time on the magnitude of the PoP effect concerns the idea of temporal context. Under an activation/suppression framework, the size of the PoP effect (as measured from trial *n*-1 to trial *n*) is related solely to the RSI between the preceding and current trial. That is, feature gains that were set on trial *n*-1 decay across the response-to-stimulus interval and residual potentiation is measured on trial *n*. Episodic retrieval theories however, argue that the probability of retrieval of the *n*-1 episode can be highly affected by contextual discriminability. Put differently, the influence of a prime episode ought to depend on some combination of the current RSI (from trial *n*-1 to trial *n*) and the prior RSI (from trial *n*-2 to trial *n*-1). The logic underlying this idea is that, when responding to trial *n*, proactive interference from trial *n*-2 can affect the retrieval of the trial *n*-1 processing episode. In the context of PoP effects, if trial *n*-1 were to occur close in time to trial *n* but far in time from trial *n*-2, then the *n*-1 processing episode would have a high level of temporal distinctiveness, and would have a high likelihood of being retrieved. In contrast, if trial *n*-1 were to occur far in time from trial *n* but close in time to trial *n*-2, then the *n*-1 processing episode would have a low level of temporal distinctiveness, and would be unlikely to be retrieved. (see Neill et al., 1992 for application of this principle to negative priming). The purpose of Experiment 2 was to provide a strong test of the temporal discriminability hypothesis within the context of a pop-out search task.

Experiment 1

The purpose of Experiment 1 was to examine the influence of RSI on the PoP effect when RSI is varied randomly on a trial-by-trial basis. It was expected that the magnitude of the PoP effect would diminish with increasing RSI. This pattern of results is predicted both by a transient decay hypothesis, but also by an episodic retrieval hypothesis in which the probability of retrieval of a prior episode decreases as time increases. However, we were particularly interested in the nature of the 'decay' of the PoP effect across time alone. Activation/suppression theories of PoP assume that the memory trace underlying the effect 'lasts' about 30 seconds (Maljkovic and Nakayama, 1994), whereas episodic retrieval theories may well predict that even after a substantial amount of time has passed between trial *n*-1 and trial *n*, there remains some probability of retrieving the *n*-1 search episode. (see Deschepper and Triesman, 1996 for an application of this logic to the negative priming effect).

Method

Participants. Participants were 32 undergraduates at McMaster University, 26 female and 6 male (mean age = 18.1 years). Participants received course credit in exchange for their participation and had normal or corrected to normal vision.

Apparatus and Stimuli. Subjects were seated approximately 57 cm away from a computer screen with their index fingers poised over each of the two response keys. Each stimulus display contained a fixation point presented centrally that subtended a visual angle of about 0.6 degrees both vertically and horizontally. Three squares were presented in a triangular format around the fixation point. On some trials two of the square were red and the third square was green, while on other trials two square were green and one was red. Each square subtended a visual angle of about 1.1 degrees. There was a gap in either the left or right hand side of each square that subtended a visual angle of about 0.6 degrees vertically. Displays remained on the screen until response, which was initiated via a key press. The response 'left' was mapped to the 'Z' key and the response 'right' was mapped to the' /' key on the keyboard. Stimuli were presented on a 15-inch Sony CRT screen. Display elements were created and presented using Presentation Software.

Procedure. Participants were instructed to indicate whether there was a gap in the left or right side of the odd-colored square in a three-element triangular display. Speed and accuracy were stressed. The experiment consisted of 480 trials that were preceded by either a 500 ms, 1000 ms, 2000 ms, 4000 ms, 8000 ms, or 16000 response-to-stimulus interval that was determined randomly on each trial. An example of the procedure is shown in Figure 1a. The first 8 trials of the experiment were used for practice and instructional purposes, and were therefore excluded from analyses.

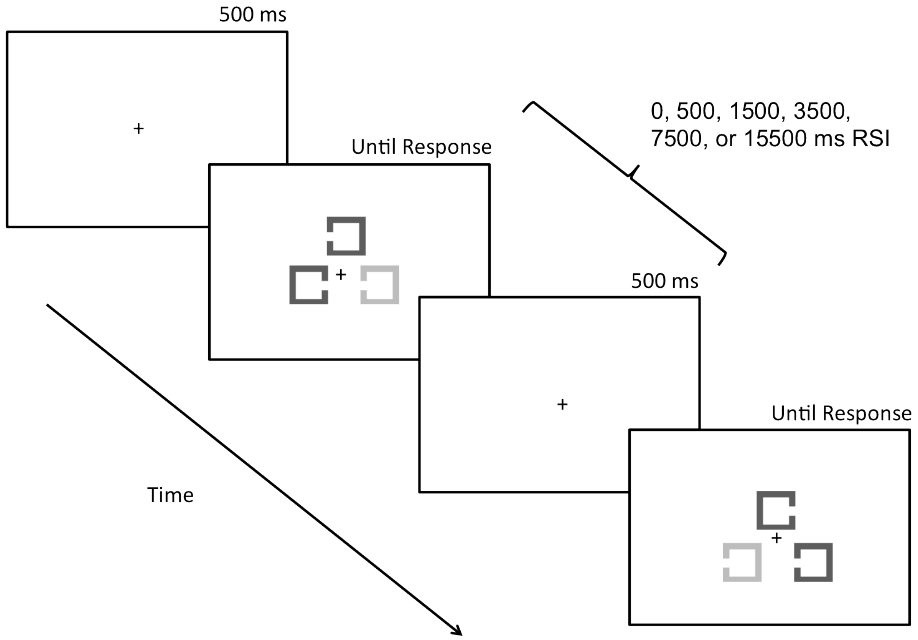

Figure 1a. An example of the procedure used in Experiment 1, in which participants respond by indicating the side of the gap in the odd colored item in each search display. The interval between response to one trial and onset of the fixation cross for the following trial was varied from 0 to 15500 ms, followed 500 ms later by the search array. These parameters resulted in 6 possible RSIs of .5, 1, 2, 4, 8, and 16 seconds.

Results

Only trials on which correct responses were made were submitted to the response time analysis. Response times (RTs) and errors for trials immediately following an error response were also excluded from analysis. All remaining RTs were submitted to an outlier procedure (see Van Selst & Jolicoeur, 1994) that excluded 3.1% of the RTs from further analysis. Mean RTs, as well as corresponding error rates, were submitted to a repeated measures analysis of variance that treated target (repeat/switch) and RSI (.5, 1, 2, 4, 8, and 16 seconds) as within-subject factors. Planned comparisons were also conducted on target repetitions and switches at each RSI to assess the presence of PoP at each time interval. Mean RTs and corresponding error rates are shown in Figure 1b.

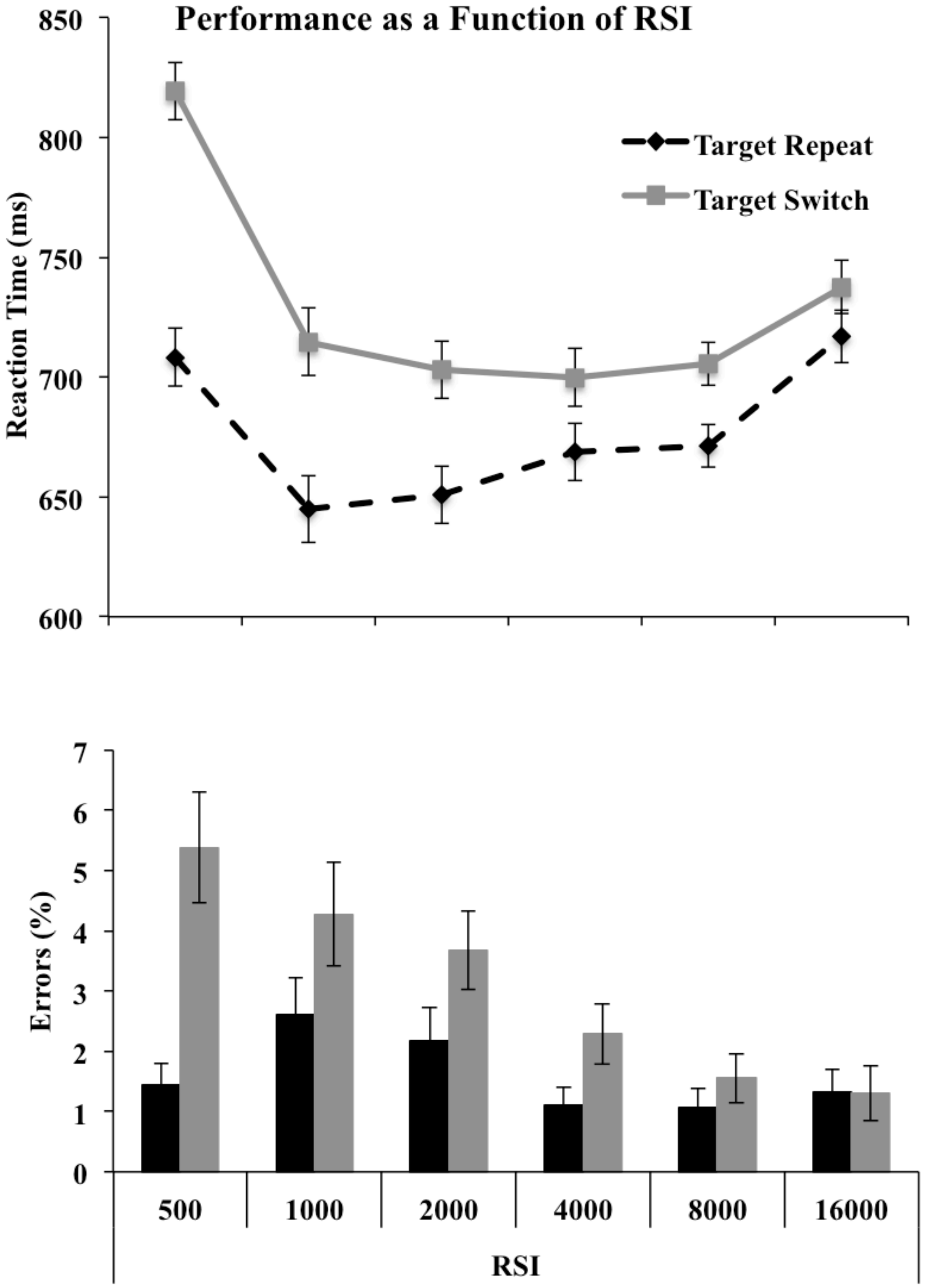

Figure 1b. Reaction time in ms (top panel) and corresponding error rates in % (bottom panel) for target color repetitions and switches as a function of the response-to-stimulus

interval between trial *n*-1 and trial *n* (in ms). Error bars represent the standard error of the mean of the priming effects (target switch – target repeat).

Response Time. The results of the omnibus ANOVA revealed a significant main effect of target, $F(1, 31) = 124.73$, $MSE = 2167.21$, $p < .0001$, with target repetitions (677 ms) being faster than switches (730 ms). There was also a significant main effect of RSI, $F(5, 155) = 23.20$, $MSE = 3341.19$, $p < .0001$. To understand the nature of the effect of RSI, comparisons of mean RT among the levels of RSI were conducted using a Tukey HSD procedure with an overall alpha criterion set at .05. Results of these comparisons revealed that mean RT was slower for the 500 ms RSI condition compared to all other RSIs, and that RT was slower for the 16000 ms RSI condition, relative to the 1000 ms RSI, the 2000 ms RSI, the 4000 ms RSI, and the 8000 ms RSI conditions.

Importantly, a significant target x RSI interaction was observed in the omnibus ANOVA, $F(5, 155) = 10.77$, $MSE = 1645.64$, $p < .0001$. We had two separate goals in looking at the PoP effects further. First, we were interested in whether a significant PoP effect was observed at each of the RSIs. To that end, we submitted target repetitions and switches to planned comparisons for each of the RSI conditions. These comparisons revealed significant PoP effects at the 500 ms RSI (111 ms), $t(31) = 10.44$, $p < .0001$, 1000 ms RSI (70 ms), $t(31) = 5.64$, $p < .0001$, 2000 ms RSI (52 ms), $t(31) = 4.95$, $p < .0001$, 4000 ms RSI (31 ms), $t(31) = 2.98$, $p = .0056$, 8000 ms RSI (34 ms), $t(31) = 4.16$, $p = .0002$, and 16000 ms RSI (21 ms), $t(31) = 2.10$, $p = .0455$. Second, we were interested in the relative size of the PoP effect across the RSI conditions. To address this issue, the PoP effects at each RSI were submitted to a Tukey HSD test with an overall alpha criterion set at .05. Results of these comparisons revealed that the PoP effect was significantly larger for the 500 ms RSI than for the 2000 ms RSI, 4000 ms RSI, 8000 ms RSI and 16000 ms RSI conditions. In addition, the PoP effect for the 1000 ms RSI was significantly larger than for the 16000 ms RSI.

Although the observed priming effects demonstrate that PoP can be measured with at least 16 seconds between search displays, we were interested in using the data further to gain an understanding of the overall time course of the PoP effect. To that end, we sought to fit a predictive function to the obtained priming effects. The best fit was obtained with a power function, $R^2 = .94675$, with a root mean squared deviation of 6.13. With increasing RSI, this function approaches a horizontal asymptote of 0 ms, but suggests that PoP effects may be non-zero well beyond the time constraints typically associated with short-term memory (Maljkovic & Nakayama, 1994). The priming effects as a function of RSI with the fitted power function can be seen in Figure 1c.

Errors. The results of the omnibus ANOVA revealed a significant main effect of target, F (1, 31) = 25.57, MSE = 7.69, $p < .0001$, with fewer errors committed on target repetitions (1.6 %) than switches (3.1 %). There was also a significant main effect of RSI, F (5, 155) = 8.59, MSE = 7.80, $p < .0001$. To examine the nature of the effect of RSI, comparisons of mean error rates among the levels of RSI were conducted using a Tukey HSD procedure with an overall alpha criterion set at .05. Results of these comparisons revealed that error rates for both the 500 ms and 1000 ms RSI conditions were significantly different from those for the 4000 ms RSI, 8000 ms RSI and 16000 ms RSI conditions. Error rates for the 2000 ms RSI condition were significantly different from those for the 8000 ms RSI and 16000 ms RSI conditions.

In addition, a significant target x RSI interaction was observed in the omnibus ANOVA, *F* (5, 155) = 5.52, *MSE* = 5.47, *p* = .0001. To assess whether the PoP effect in error rates was significant at each of the RSIs, planned comparisons were conducted for target repetitions and switches for each of the RSIs. These comparisons revealed that more errors were committed on target switches than on target repetitions for the following RSI's: 500 ms (3.9 %), *t* (31) = 4.73, *p* < .0001, 1000 ms (1.7 %), *t* (31) = 2.14, *p* = .0406, 2000 ms (1.5 %), *t* (31) = 2.90, *p* = .0068, 4000 ms (1.2 %), *t* (31) = 2.25, *p* = .0321. No significant differences in error rates emerged for the 8000 ms RSI condition (0.5 %) or the 16000 ms RSI condition (0.0 %). To examine the nature of the target x RSI interaction in the pattern of error rates, differences in error rates between target repetitions and switches at each RSI were submitted to a Tukey HSD test with an overall alpha criterion set at .05. Results of these comparisons revealed that the PoP effect in error rate for the 500 ms RSI condition differed from those for the 2000 ms RSI, 4000 ms RSI, 8000 ms RSI and 16000 ms RSI conditions.

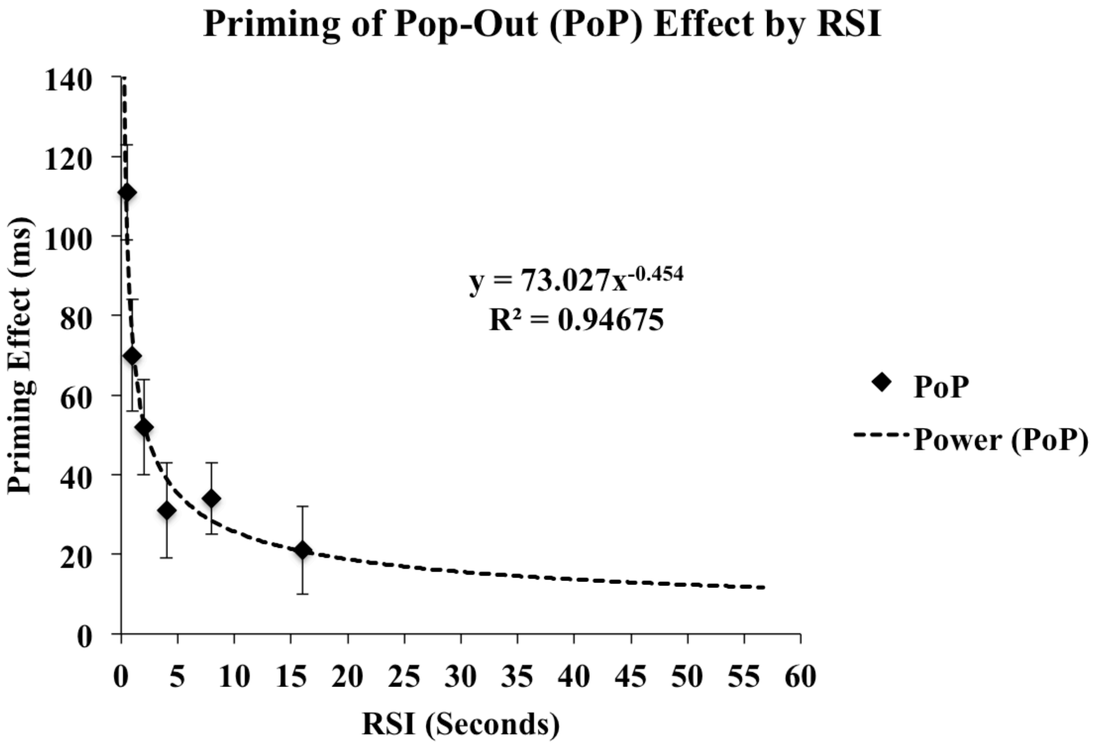

Figure 1c. Priming of Pop-Out effects (target switch – target repeat) are shown (filled diamonds) as a function of the response-to-stimulus interval (RSI) from the previous to the current trial. Error bars represent the standard error of the priming effects. Also shown is the curve of the fitted power function (dashed line) that best describes the data.

Discussion

The purpose of Experiment 1 was to provide a direct measure of the effect of RSI on the magnitude of the PoP effect. PoP has been argued to reflect the operation of a transient memory trace that decays across time and ceases to impact performance after 30 seconds at the most (Maljkovic & Nakayama, 1994). Until now, however, the duration of the memory that underlies PoP has never been directly assessed in the absence of intervening items. The two leading theoretical accounts of PoP predict that as time alone passes, the magnitude of the PoP effect should diminish. However, activation/suppression theories argue that the feature gains associated with target-defining information return to some baseline level of activation after around 30 seconds, whereas episodic retrieval theories make no such prediction.

The results of Experiment 1 clearly show two things: (1) the magnitude of the priming of pop-out effect does indeed diminish as RSI increases, however the majority of this 'decay' occurs within the first second, post-response, after which the reduction of the PoP effect occurs much more slowly across time; (2) the effect of RSI on the magnitude of the PoP effect is best described by a power-law function that suggests that PoP could occur well beyond the conventional time constraints of short-term memory.

The idea that PoP may last longer when time alone, rather than time and a series of intervening search experiences, passes between the influencing and current trials, suggests that the 'duration' across which PoP can be measured may be highly dependent on intervening search experiences. This idea can be interpreted in two ways: (1) the feature gains associated with a given search trial may somehow decay more slowly when there are no intervening events between the influencing (*n-i*) and current (*n*) trials. (2) the probability of retrieval of a given prior episode may be diminished by intervening items due to retroactive interference. The general notion that PoP effects are sensitive to interference was examined in more detail in Experiment 2.

Experiment 2

Experiment 2 aimed to examine the influence of proactive interference on PoP by way of a manipulation of temporal distinctiveness. Temporal distinctiveness has been shown to affect the magnitude of priming effects in other domains such as negative priming (Neill et al., 1992). Specifically, when the ratio of the current RSI (RSI) to previous RSI (PRSI) is small, priming effects are expected to be larger than when that ratio is large. This prediction follows because a small RSI to PRSI ratio implies that the *n*-1 episode occurs closer in time to trial *n* than to trial *n*-2. As a result, proactive interference from trial *n*-2 on retrieval of the *n*-1 episode is minimal. To that end, inter-trial RSI was manipulated randomly from one trial to the next such that a search array could be preceded by either a short or a long RSI. If temporal distinctiveness impacts the PoP effect, then the previous trial RSI ought to modulate the PoP effect, resulting in the following predictions for the magnitude of the PoP effect as a function of PRSI:RSI ratio: 500:8000 < 8000:8000, and 500:500 < 8000:500. In contrast, if temporal distinctiveness does not impact the PoP effect, then only the current RSI should affect the magnitude of the PoP effect, resulting in the following predictions for the magnitude of the PoP effect as a function of PRSI:RSI ratio: 500:8000 = 8000:8000 < 500:500 = 8000:500.

Method

Participants. Participants were 24 undergraduates at McMaster University, 20 female and 4 male (mean age = 18.6 years). Participants received course credit in exchange for their participation and had normal or corrected to normal color vision.

Procedure. The apparatus, stimuli and procedure were identical to that of Experiment 1 with the following exceptions. Search trials were preceded by a short (500 ms) RSI, or a long (8000 ms) RSI, intermixed randomly. An example of the sequence of trial types is shown in Figure 2a.

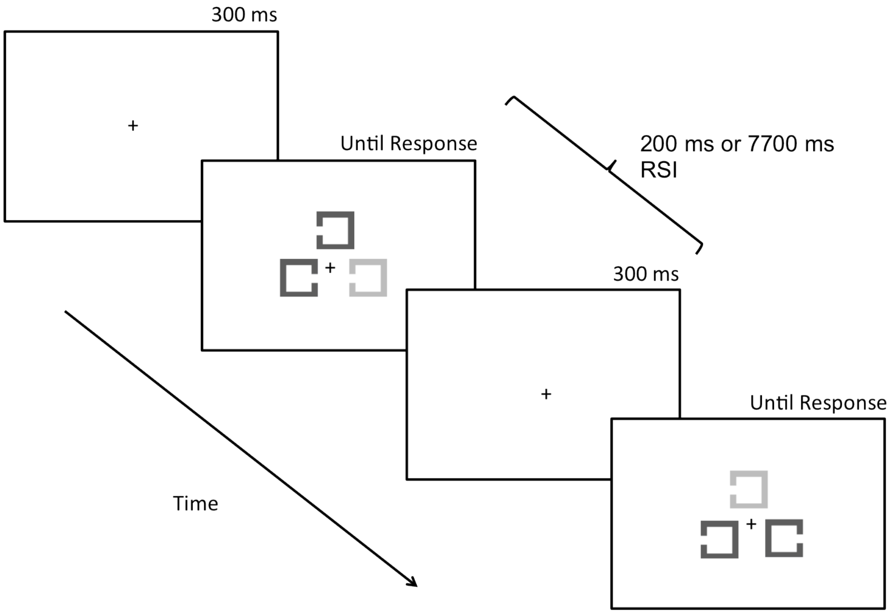

Figure 2a. An example of the procedure used in Experiment 2, in which participants responded by indicating the side of the gap in the odd colored item in each search display. The interval following response to one trial and onset of fixation for the next trial was either 200 ms or 7700 ms, at which point a fixation cross appeared 300 ms prior to onset of the search array. These parameters resulted in two RSIs of 500 ms and 8000 ms.

Results

As each trial type is contingent on the nature of the previous trial type, trials on which errors were made and trials following errors were omitted from the analysis. The remaining correct RTs were submitted to an outlier elimination procedure that eliminated 2.8 % of observations (Van Selst & Jolicoeur, 1994). Mean RTs were then computed from the remaining observations, and these mean RTs and corresponding error rates were submitted to repeated measures analyses of variance that treated target (repeat/switch), RSI (long/short), and PRSI (long/short) as within subject factors. Mean RTs and corresponding error rates are shown in Figure 2b.

Response times. The analysis of RTs revealed a main effect of target, *F* (1, 23) = 115.30, *MSE* = 1585.62, *p* < .0001, with response times being faster on target repeat (684 ms) than on target switch (745 ms) trials. There was a significant main effect of RSI, *F* (1, 23) = 5.85, *MSE* = 6005.01, *p* = .024, with faster responses on long RSI trials (701 ms) than on short RSI trials (728 ms). There was also a significant main effect of PRSI, *F* (1, 23) = 4.62, *MSE* = 1378.95, *p* = .042, with response times being faster when the PRSI was long (708 ms) than when it was short (720 ms).

Importantly, there was a significant target x RSI interaction, *F* (1, 23) = 45.68, *MSE* = 1653.05, *p* < .0001. To examine this interaction further, paired comparisons were conducted that compared target repetitions and switches separately for the long and short RSI conditions. These comparisons revealed significant effects of target for both the long, *t*(23) = 3.68, *p* = .0013, and short RSI, *t*(23) = 10.21, *p* < .0001, conditions, meaning that the target x RSI interaction is driven by a smaller PoP effect for the long (22 ms) compared to the short (101 ms) RSI condition. Importantly, there was no PRSI x target interaction, suggesting that the PoP effect was not affected by our manipulation of temporal distinctiveness.

Error rates. The analysis of error rates revealed a significant effect of target, *F* (1, 23) = 11.17, *MSE* = 5.04, *p* = .0028, with more errors committed on target switches (3.3 %) than on target repetitions (2.2 %). There was also a main effect of RSI, *F* (1, 23) = 10.83, *MSE* = 11.65, *p* = .0032, with more errors committed on short RSI trials (3.6 %) than on long RSI trials (1.9 %). There was also a significant target x RSI interaction, *F* (1, 23) = 6.27, *MSE* = 5.01, *p* = .0199. To examine this interaction further, paired comparisons were conducted on target repetitions and switches, separately for long and short RSI trials. These comparisons revealed no effect of target for the long RSI condition (0.3 %), *t* < 1, but did reveal a significant effect of target for the short RSI condition (1.9 %), *t* (23) = 3.76, *p* = .001. There were no significant effects in error rates involving the PRSI variable.

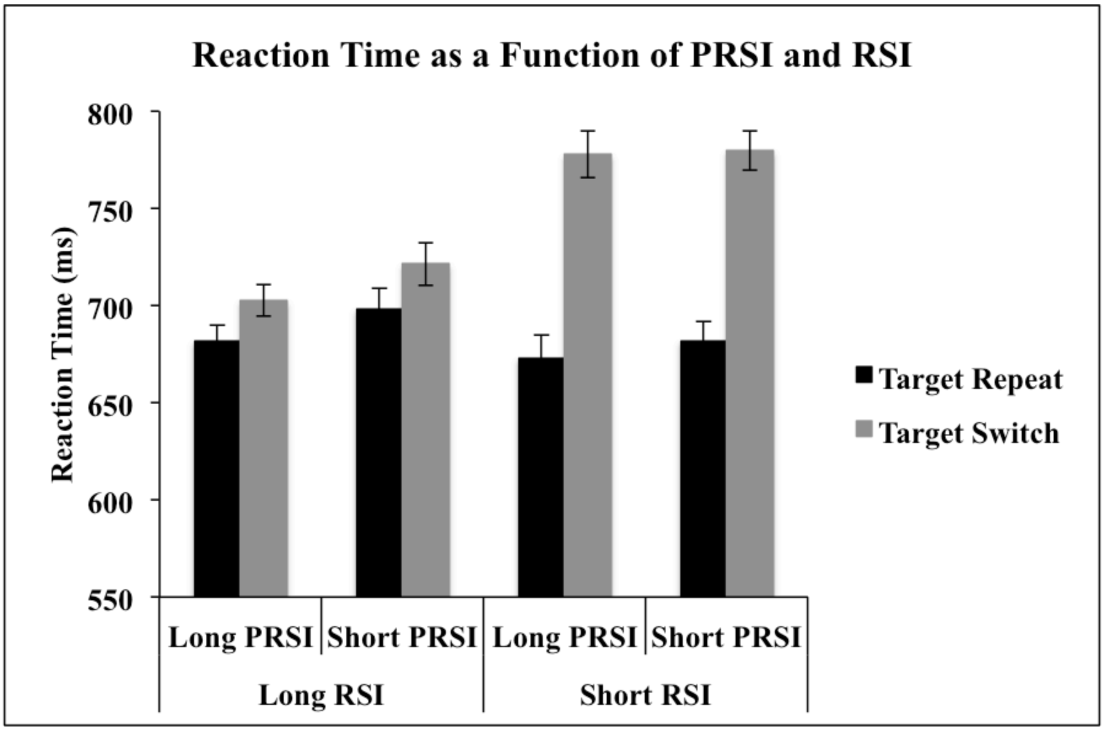

Figure 2b. Reaction times (in ms) are shown for target color repetitions and switches as a function of whether the response-to-stimulus interval (RSI) from trial *n*-1 to trial *n* was long (8000 ms) or short (500 ms) and whether the previous response-to-stimulus interval (PRSI) from trial *n*-2 to trial *n*-1 was long (8000 ms) or short (500 ms). Error bars represent the standard error of the priming effects (target switch – target repeat).

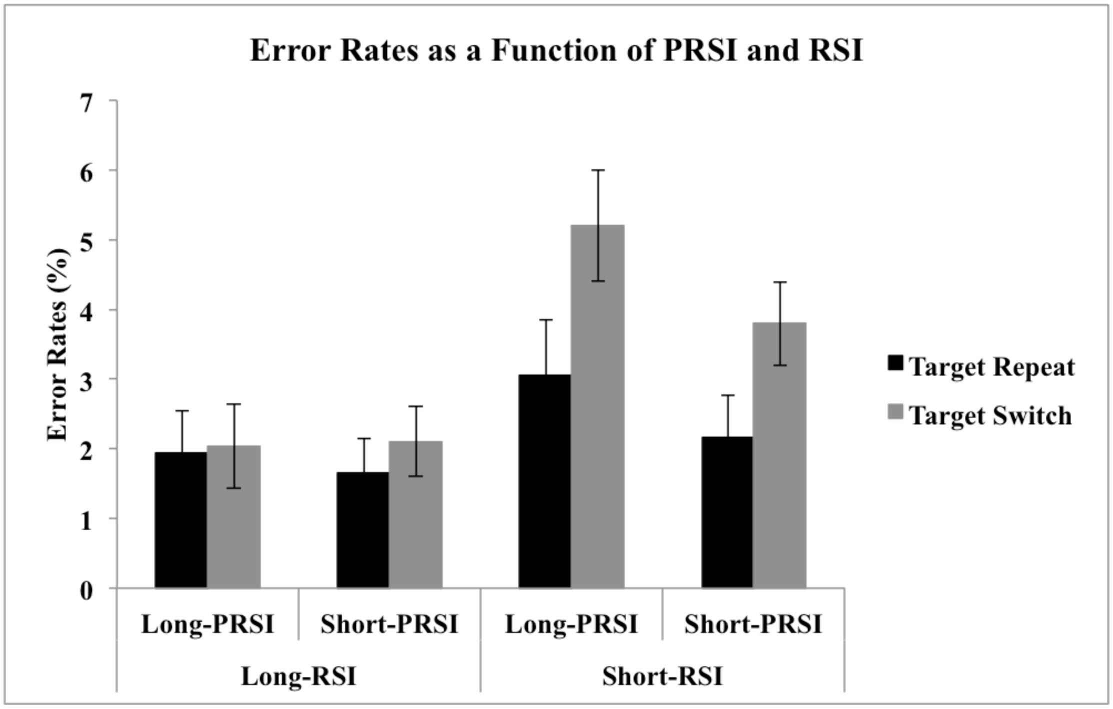

Figure 2c. Error rates (%) are shown for target color repetitions and switches as a function of whether the response-to-stimulus interval (RSI) from trial *n*-1 to trial *n* was long (8000 ms) or short (500 ms) and whether the previous response-to-stimulus interval (PRSI) from trial *n*-2 to trial *n*-1 was long (8000 ms) or short (500 ms). Error bars represent the standard error of the priming effects (target switch – target repeat).

Discussion

The purpose of Experiment 2 was to assess whether the PoP effect would be sensitive to a strong manipulation of temporal distinctiveness. If so, then the PoP effect ought to have varied as a function of PRSI, with larger PoP effects for longer values of PRSI. The general idea is that longer PRSIs increase the temporal discriminability of the trial *n*-1 episode, making its retrieval more likely. The results were clear: PoP was strongly affected by the RSI from trial *n*-1 to trial *n*, but was not affected by the previous

RSI from trial *n*-2 to trial *n*-1. As such, we must conclude that although temporal distinctiveness has been shown to modulate trial-to-trial priming effects in other notable performance tasks such as negative priming (see Neill et. al, 1992), it does not appear to modulate the PoP effect.

General Discussion

One of the primary aims of the present study was to examine the time course of PoP effects in the absence of interference from intervening items. The results of Experiment 1 demonstrated clearly that the magnitude of the PoP effect was significantly smaller at long RSIs than short RSIs. This result suggests that time alone can diminish the effect of trial *n*-1 on trial *n*, in the absence of interference from intervening search experiences. This result is predicted by both transient activation/suppression as well as episodic retrieval theories of PoP. However, the majority of this reduction in the PoP effect occurred within the first second post-response, after which the PoP effect diminished slowly across time in accord with a power-law function. Indeed, this model suggests that the PoP effect may be observed across time intervals far outside the conventional time constraints of short-term memory. We take these results as evidence favoring the view that the PoP effect is at least partly determined by long-term episodic memory representations.

In line with this view, the aim of Experiment 2 was to examine whether PoP effects are sensitive to a manipulation of temporal distinctiveness. To address this issue, the sensitivity of PoP effects to both RSI and PRSI were examined. The results again revealed that the PoP effect is sensitive to RSI, with smaller PoP effects for longer RSIs. However, the PoP effect did not vary as a function of PRSI, indicating that proactive interference from the trial *n*-2 episode plays no discernible role in the impact of trial *n*-1 on trial *n.*

The results of the experiments reported here have important implications for leading theoretical interpretations of the PoP effect. PoP is argued by some to reflect a transient short-term memory effect that exerts its influence on performance for about 30 seconds post-response (Maljkovic & Nakayama, 1994; Lee et al., 2009). Others have argued that PoP is driven by the retrieval of bound episodic memory representations that are likely stored temporarily in short-term visual working memory (Hillstrom, 2000; Huang et al., 2004). Recently, some researchers have argued that both activation/suppression of short-term representations, as well as short-term episodic retrieval, impact PoP effects, with the relative influence of one over the other depending on the particular task demands (Lamy et al., 2010; also see Kristjansson & Campana, 2010 for a recent review of this idea). Although these theories (and variants thereof) differ in many respects, all accept the idea that the memory mechanism underlying PoP can only exert its influence for a short amount of time (about 30 seconds at the most). Yet, the influence of time alone on the PoP effect has not been directly measured. To our knowledge, Experiment 1 of the present study was the first test of this issue.

To this end, it is worth noting that evidence for the short-term 'duration' of the PoP effect has been derived from experiments in which PoP was observed across a window of no more than eight trials. This window has been translated to a duration of about 30 seconds simply by adding together the average response time per trial and the sum of the inter-trial intervals (see Maljkovic & Nakayama, 1994, Experiment 5). Such an estimate places the PoP effect firmly within the realm of short-term memory. This conclusion however, is based on studies in which the passage of time has been confounded by the presence of intervening items. The present experiment demonstrates that PoP may well last significantly longer than 30 seconds, provided that there are no intervening search experiences between trial *n* and *n*-1. It is reasonable to conclude therefore, that the magnitude of PoP is dependent on both the passage of time as well as the number of intervening search experiences between the current and influencing trial. At the same time, we have learned that the PoP effect is not sensitive to proactive interference differences introduced by varying the temporal interval preceding trial *n*-1. Given the absence of evidence of proactive interference effects on the PoP effect, a reasonable and promising line of investigation for future study is the issue of retroactive interference introduced by intervening search items between trial *n*-1 and trial *n*.

CHAPTER 4: Perceptual Distinctiveness Produces Long-Lasting Priming of Pop-Out

Thomson, D.R. & Milliken, B. (submitted). *Psychonomic Bulletin & Review*.

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PREFACE

Chapter 4 presents the results of a single experiment in which the mechanism of ‘forgetting’ responsible for the short-lived nature of PoP is assessed. The two leading theories of PoP make different claims about the duration of the memory representation underlying the effect. Activation/suppression theories claim that the memory trace laid down on each search experience decays passively across time, while episodic retrieval theories argue that as interference from intervening items increases, the probability of retrieval of a particular prior experience decreases. The retrieval interference hypothesis was tested by creating rare search displays that were perceptually distinct from the intervening common displays. PoP was observed from one rare search display to the next, across twice as many intervening items as has previously been shown. This is taken as initial evidence for the retrieval interference account of the short-lived nature of PoP. This is taken as further evidence that PoP may be mediated by episodic memory representations.

Abstract

Maljkovic and Nakayama (1994) were the first to demonstrate memory influences in singleton search from one trial to the next, an effect they termed priming of pop-out (PoP). This effect was described as resulting from the implicit persistence of a transient

memory trace, the influence of which could be observed for up to 5-8 subsequent trials. The seemingly short-lived nature of this priming effect has been critical in terms of the theoretical interpretations of PoP; some researchers have attributed PoP to passive decay of feature gains associated with target-defining information. The present study examined the influence on PoP of ‘rare’ search trials that were perceptually distinct with respect to the other ‘common’ trials. Long-lasting (*n*-16) PoP was observed for rare trials that were composed of distinct target/distracter colors, suggesting that PoP can be observed across at least twice as many trials as has previously been reported. Thus, the time span across which PoP can be measured depends on more than time, a result that must be accommodated by theoretical accounts of PoP

Visual search processes are fundamental to the selection of relevant information in our perceptual environment. Although visual search is ubiquitous in everyday life, the nature of the underlying mechanisms that allow us to search efficiently remains a topic of intense scientific study. This study is aimed in particular at the nature of the processes that contribute to efficient (or pop-out) search performance. Although pop-out search was once thought of as depending entirely on pre-attentive perceptual processing (Treisman & Gelade, 1980), a growing body of evidence suggests that it is also affected by short-term memory representations. Assessing the short-lived nature of memory representations in singleton search is the primary purpose of the work reported here.

In a series of experiments, Maljkovic and Nakayama (1994, 1996, 2000) were the first to demonstrate the role of memory in singleton search. In their experiments, participants searched for an odd-colored diamond amongst two homogeneous distracters and indicated whether it was truncated on the left or right. Performance was analyzed on the current trial as a function of the repetition or alternation of the target-defining feature from the previous trial. Importantly, they found that search times were faster for repeated target colors compared to switches, an effect they termed priming of pop-out (PoP). PoP, it was argued, reflects the operation of a short-term, implicit memory trace that contains target-defining feature information. This memory trace was shown to affect performance for 5-8 subsequent trials (Maljkovic & Nakayama, 1994, Experiment 5) and was argued to affect performance without awareness (Maljkovic & Nakayama, 2000).

Theoretical interpretations of the memory mechanism underlying the PoP effect have been forwarded recently that bear a close resemblance to the original interpretation of the effect offered by Maljkovic and Nakayama. These theories will be referred to collectively as activation/suppression accounts of PoP. These theories argue that when pop-out search is performed, abstract feature representations that define the target are modified. For example, if the task is to locate the odd-colored item in a display and it happens to be green, while distracters are red, then a corresponding feature gain for 'green' and feature suppression for 'red' will occur. These feature activation changes then begin to return back to baseline, post-response, such that if they are still activated or suppressed when the next search array appears, costs or benefits to performance can be observed (Goolsby & Suzuki, 2001; Lamy, Antebi, Aviani & Carmel, 2008; Lee, Mozer & Vecera, 2009).

An alternative theoretical account of PoP relies on memory retrieval processes. For example, some researchers have found that priming effects in singleton search from one trial to the next can depend not only on the repetition/alternation of the target-defining feature, but also on target irrelevant feature repetitions, such as the repetition/alternation of the response feature (Hillstrom, 2000), irrelevant spatial frequency (Kristjansson, 2006) and irrelevant color in an odd-sized pop out task (Huang, Holcombe & Pashler, 2004). The fact that repeating or alternating these low-level features from one trial to the next produces interactions in performance (sometimes in line with partial-match effects; see Hommel, 1998, 2004) has led to the conclusion that perhaps PoP is driven by the implicit and automatic retrieval of bound episodic memory representations, akin to instances (Logan 1988, 1990) or event files (Hommel, 1998). Hillstrom (2000) argued that if these episodic representations drive PoP, they are stored temporarily in visual short-term working memory (VSWM) on a given trial, and are subsequently recruited from VSWM on the next trial on the basis of some crude 'pre-attentive' map of the current display that shares low-level perceptual attributes with the episode stored in VSWM. Therefore, in contrast to feature gain modulations that carry forward in time, episodic representations are retrieved from memory by the perceptual attributes of the current search display.

Despite the important differences between current episodic retrieval and activation/suppression accounts of PoP, central to both accounts is the idea that priming in singleton search is a short-lived phenomenon. For example, as mentioned earlier, PoP has been shown to exert its influence for up to 5-8 subsequent trials (Malkjovic & Nakayama, 1994, Experiment 5) at the most (Geyer, Muller & Krummenacher, 2007 found PoP for location that lasted only four trials, Hillstrom, 2000 found PoP for color that lasted only three trials). Feature gains therefore, are argued to 'decay' within a few trials whereas episodes can only be retrieved while they are in VSWM. In effect, it seems as though there is consensus among researchers who study PoP that long-term episodic memory representation known to impact performance in less efficient (conjunctive) search scenarios (see Chun & Jiang, 1998; Chun & Phelps, 1999) do not contribute to PoP.

Indeed, theoretical accounts of priming effects in human performance tasks have often been constrained by an assumption that they are driven by fleeting short-term memory representations. For example, inhibition of return (IOR) (see Posner & Cohen, 1984) was long assumed to reflect the temporary 'suppression' of attention to a previously attended location. However, Tipper, Grison and Kessler (2003) found IOR effects that survived a number of intervening trials, when complex displays (faces) were used. Similarly, Wilson, Castel and Pratt (2006) found long-term IOR effects by presenting ‘rare’ IOR trials that appeared in different spatial locations than the intervening ‘common’ trials. Such effects have been taken as evidence for the role of memory retrieval processes in producing IOR that can be long-term in nature. Following this line of thinking, the present study examined whether perceptually distinct ‘rare’ trials in a color-singleton search task might produce long-term PoP effects; that is, PoP effects that survive more than 5-8 intervening trials. Such a finding would have significant theoretical implications for current accounts of the memory mechanism underlying PoP.

The Present Study

In order to assess whether PoP can be observed across a large number of intervening items, ‘rare’ search arrays were created that were perceptually distinct with respect to the intervening ‘common’ trials. Thus, participants performed a color pop-out search task in which ‘common’ trials were composed of one target/distracter color set (i.e. red/green or blue/yellow) while rare trials (which appeared every 16th trial) were composed of the other target/distracter color set. Although we expected priming on the standard ‘common’ trials to last for about 5-8 subsequent trials, as has been shown previously, we hypothesized that ‘rare’ trials may constitute perceptually distinct contexts for which longer-lasting PoP may be observed.

Method

Participants. 24 undergraduate students from McMaster University (11 male, 13 female, mean age = 20.8 years) participated in exchange for either course credit or $10 CAD for one hour of participation. All participants had normal or corrected to normal vision.

Apparatus/Stimuli. Search arrays were presented using Presentation software on a Dell 15 inch CRT monitor connected to a Dell PC. Each search array contained three squares that subtended a vertical and horizontal visual angle of 1.1 degrees. Each square contained a gap in either the left or right side that subtended a visual angle of 0.6 degrees vertically. Each search array was arranged in an equilateral triangle with a fixation cross at the center, which subtended a vertical and horizontal visual angle of 0.6 degrees. Each array contained two homogeneous distracter items and one target item (i.e., if the target item was randomly assigned to be red on a given trial, the distracters were presented in green). Common trials were composed of one target-distractor color set (e.g. red/green or blue/yellow) while rare trials were composed of the other target-distractor color set. This assignment of color sets to common and rare trials was counter-balanced across participants.

Procedure. Participants were seated approximately 57 cm from the computer screen and were instructed that on each trial they would see three squares arranged in a triangular formation around a central fixation cross. They were asked to locate the odd-colored square in each display and indicate whether it had a gap in the left or right side as quickly and accurately as possible. Participants indicated a 'left' response by hitting the 'z' key with their left index finger and indicated a 'right' response by hitting the '/' key with their right index finger.

Each stimulus array was preceded by a fixation cross that appeared 300 ms before the search array and remained on the screen until a response was made, at which point the stimulus array, together with the fixation cross, disappeared. The screen then remained blank for 500 ms until the fixation-cross appeared again to signal the next trial. This resulted in an 800 ms response-to-stimulus interval between search arrays. Participants completed 15 search trials composed of one target/distractor color set (red/green or blue/yellow) and then completed one search trial composed of the other target/distractor color set. This sequence was repeated 100 times for a total of 1600 trials (1500 common, 100 rare). The first eight trials in the experiment were used for practice and instructional purposes, resulting in 1592 experimental trials. Participants were given the opportunity to take a break every 200 trials and the experiment resumed whenever the participant pressed the space bar to initiate the next block. The trial sequence is presented in Figure 1a.

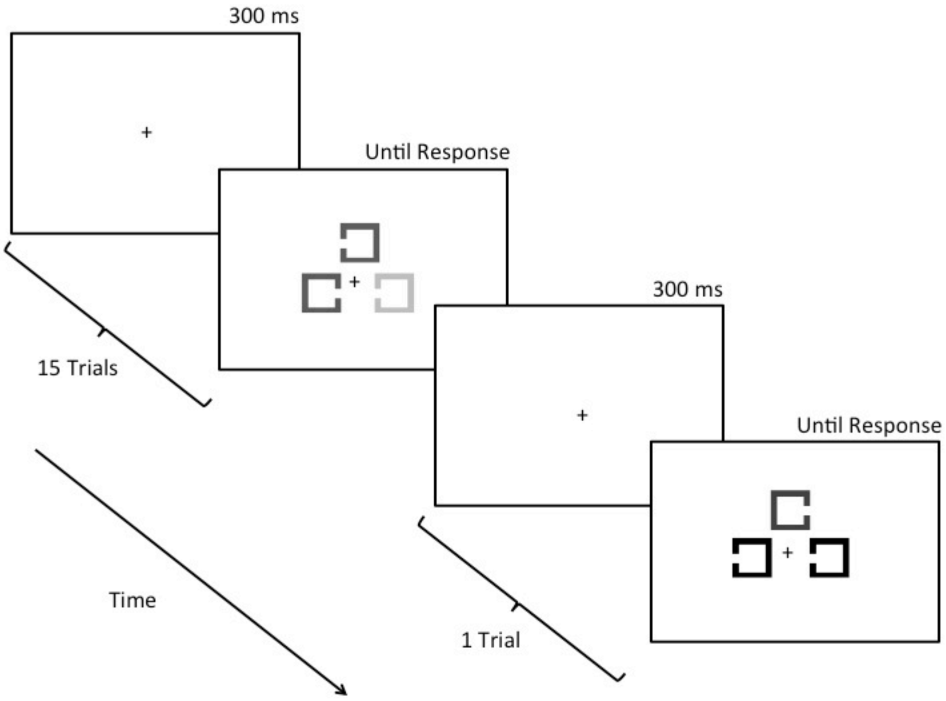

Figure 1a. A depiction of the procedure used in the present study, in which participants locate and respond to the odd-colored square in each display. Stimulus displays remained on the screen until a response was executed and then after a 500 ms blank interval, the

fixation cross for the next search array appeared. Participants performed 15 trials composed of one target/distracter color combination ('common' trials; either red/green or blue/yellow) followed by one trial composed of the other target/distracter color combination ('rare' trials).

Results

Only trials on which correct responses were made were submitted to the response time analysis. As each experimental condition is contingent on the nature of the previous trial type, response times and errors for trials immediately following an error response were also excluded from analysis. All remaining RTs were submitted to an outlier procedure that excluded RTs based on outlier criteria that varied as a function of cell size (see Van Selst & Jolicoeur, 1994). Separate cells of observations were created using RTs for common trials as a function of whether the target color repeated or switched in relation to the immediately preceding trial (*n*-1), to the trial just before the immediately preceding trial (*n*-2), and so on, back to trial *n*-9. Note that this analytic strategy implied that any particular response time could contribute to the mean RT for multiple preceding trial types (e.g., trial *n* RT might contribute both to the target repeat mean RT for the *n*-1 preceding trial type, but to either the target repeat or target switch mean RT for the *n*-2 preceding trial type). Similarly, separate cells of observations were created using RTs for rare trials as a function of whether the target color repeated or switched from the immediately preceding rare trial (*n*-16) as well as prior influencing rare trials (*n*-32 and *n*-48). Overall, the outlier analysis eliminated 2.7% of the observations. Mean RTs were then computed from the remaining observations. These mean RTs are shown in Figure 1b. Error rates were computed in a similar manner for first-order sequence effects (*n*-1 for common trials, *n*-16 for rare trials). A summary of error rates for target color repetitions and switches on common trials as a function of the immediately preceding common trial (*n*-1), and on rare trials as a function of the immediately preceding rare trial (*n*-16), are shown in Table 1.

Table 1. Mean error rates (%) and standard deviations for target color repetitions and alternations on trial n as a function of the previous trial (*n*-1 for common trials, *n*-16 for rare trials).

	Trial Type			
	Common		Rare	
	μ	(SD)	μ	(SD)
Target Repeat	3.8	(3.3)	3.5	(3.7)
Target Switch	5.3	(4.1)	2.9	(3.1)

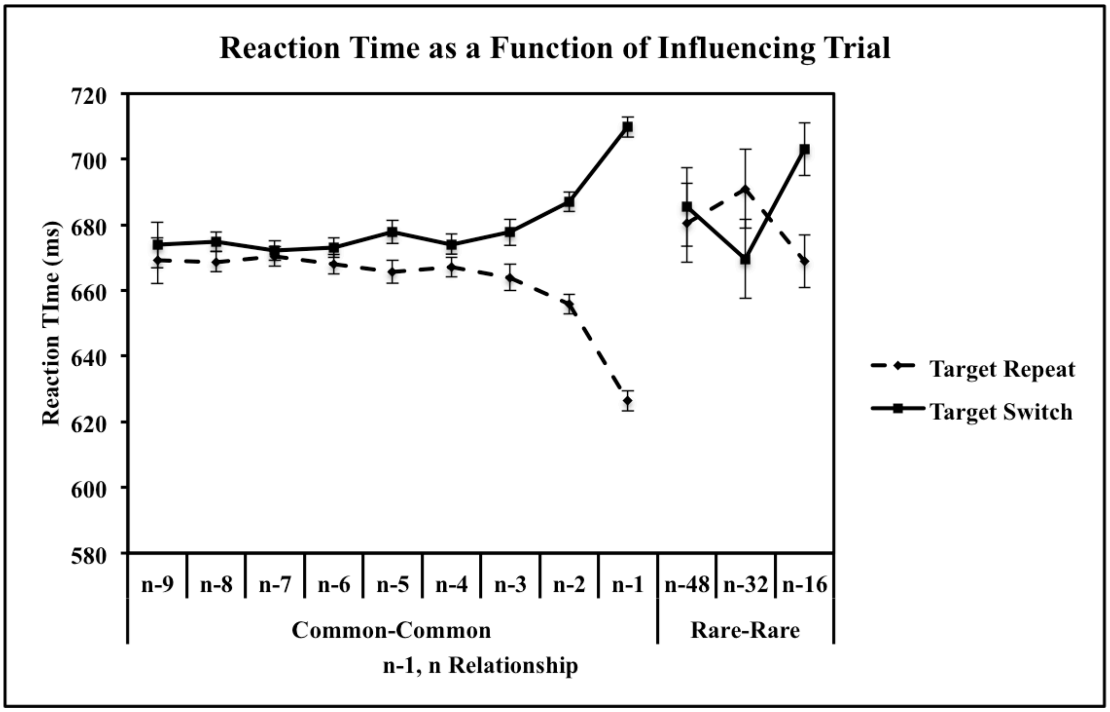

Figure 1b**.** Response times (ms) are depicted for target repetitions and switches for common-common and rare-rare trial types on trial *n* as a function of influencing trial.

Error bars represent the standard error of the priming effects (target switch – target repeat).

Our analyses centered on three issues. First, we compared performance for the common and rare trials, simply to evaluate whether this factor affected performance overall. Second, we examined performance on common trials, excluding those trials in which the preceding trial was a rare trial. Our objective here was to evaluate whether the data replicate the results reported in prior studies that have not included rare trials. Third, and most important, we examined performance on rare trials to evaluate whether PoP effects can occur relative to other rare trials that happened 16 trials prior.

Response times. There was a significant difference between RTs for common and rare trials, $t(23) = 2.58$, $d = .17$, $p = .0166$, with responses being faster on common trials (668 ms) than rare trials (686 ms). To evaluate the magnitude of the PoP effect for common trials as a function of the previous influencing common trials, planned comparisons were conducted that compared target repetitions and alternations. These analyses indicated significant PoP effects on the current trial as a function of the following influencing trials: *n*-1 (83 ms), $t(23) = 11.87$, $d = .81$, $p < .0001$, *n*-2 (31 ms), $t(23) = 9.90$, $d = .30$, $p < .0001$, *n*-3 (14 ms), $t(23) = 4.76$, $d = .13$, $p < .0001$, *n*-4 (7 ms), $t(23) = 2.50$, $d = .07$, $p = .0201$, *n*-5 (12 ms), $t(23) = 3.65$, $d = .12$, $p = .0013$, and *n*-8 (6 ms), $t(23) = 2.25$, $d = .06$, $p = .0341$, and no significant PoP effects as a function of the following influencing trials: *n*-6 (5 ms), *n*-7 (2 ms) and *n*-9 (5 ms). These results mirror those of prior studies in which the target color on the current trial has been shown to affect performance for about 5-8 subsequent trials (Malkjovic & Nakayama, 1994).

Of primary interest to the present study is whether PoP can be observed from one rare trial to the next, across 15 intervening common trials. To assess the magnitude of the PoP effect on the current rare trial as a function of the previous influencing rare trials, planned comparisons were conducted that compared target repetitions and alternations. These analyses revealed a significant PoP effect at *n*-16 (34 ms), $t(23) = 2.92$, $d = .29$, $p = .0077$, but not at *n*-32 (-21 ms) or *n*-48 (5 ms). This result indicates that although PoP for common trials diminished following an interval containing 5-8 common trials, PoP was still measurable from one rare trial to the next following an interval between the two rare trials that contained 15 common trials.

Error rates. The analysis of error rates revealed that significantly more errors were committed on common trials (4.5 %) than on rare trials (3.2 %), $t(23) = 3.11$, $d = .41$, $p = .0049$, suggesting perhaps that the onset of a rare trial led participants to respond both more slowly and accurately overall. In the analysis of the common trials, more errors were committed on target switches (5.3%) than target repetitions (3.8 %), $t(23) = 4.65$, $d = .39$, $p < .0001$, relative to the immediately preceding trial (*n*-1). In the analysis of the rare trials, there was no significant difference in error rates for target repetitions (3.5 %) and switches (2.9 %) relative to the immediately preceding rare trial (*n*-16).[1]

Discussion

The primary purpose of the present study was to examine whether perceptually distinct search arrays in a color pop-out task would yield priming of pop-out across a large number of intervening items. In previous studies, PoP has been shown to last for about 5-8 trials (Maljkovic & Nakayama, 1994, Experiment 5) and thus has been classified as a short-term priming effect. Based on the short-term nature of this effect, theoretical interpretations of the memory mechanism underlying PoP have posited that feature gains associated with target-defining features decay within 5-8 trials on the one hand (Maljkovic & Nakayama, 1994; Lee, et al., 2009), or that bound episodic representations are retrieved from a short-term memory store on the other hand (Hillstrom, 2000; also see Huang, et al., 2004). The work reported here follows the logic of similar studies that have sought long-term priming effects in other attention and performance domains (e.g., IOR; see Wilson, Castel & Pratt, 2006). In particular, the aim of the current study was to examine whether perceptually distinct 'rare' trials would foster context-specific retrieval processes that produce PoP effects across relatively long temporal delays.

The results were quite clear, in that PoP effects were shown to persist for 5-8 trials for the common search arrays, which parallels the findings from other singleton search studies. Importantly though, significant PoP emerged when measured from one rare trial to the next in the present study, despite the fact that such an effect was measured across 15 intervening search trials. PoP therefore can be said to last for at least 16 trials (twice as long as has been shown in previous work) provided that trial n and trial *n-i* are perceptually distinct with respect to the intervening search arrays.

The novel finding of long-lasting PoP observed here has important implications for the theoretical accounts of PoP offered in the introduction. In light of the present results, an account of PoP that hinges on activation/suppression of feature gains from one trial to the next must somehow argue that feature gains decay at a much slower rate for the rare than for the common trial type. An account of PoP that hinges on the retrieval of bound episodic representations must concede that these representations are likely not recruited from VSWM, (assuming that 16 search experiences is well beyond the capacity limitations of such a store). In either case, the important point is that long-lasting PoP effects delivered by use of perceptually distinct contexts challenge any notion that PoP effects depend on short-term memory representations that decay passively across time.

It is worth noting that there has been increasing interest in the idea that episodic retrieval processes can contribute to PoP effects. One recent proposal assumes activation and suppression processes govern PoP effects under many conditions, but that when pop-out search is more difficult (i.e., targets are made less salient with respect to distracters), 'bound' episodic representations can be recruited from memory and consequently impact performance (Asgeirsson & Kristjansson, 2011; Lamy, Zivony & Yashar, in press; see also Kristjansson & Campana, 2010). Nonetheless, these dual-process accounts of priming in singleton search are still constrained by the seemingly transient nature of the representations that drive PoP and may have to be revised somewhat in light of the findings presented here. As a result, it may be more suitable to regard the effects of perceptually distinct search trials here as providing contexts with which to retrieve similar prior experiences from memory, without regard for the distinction between short-term and long-term memory. Clearly, a great deal more work is necessary to explore what types of perceptual/contextual distinctiveness produce the long-lasting PoP observed here. Nonetheless, the current experiment on its own makes the point that PoP can be measured across intervals that are at least twice as long as has previously been shown.

Footnotes

[1] The reader may note that although there is no statistical difference in error rates between target repetitions and switches for rare trials, numerically the difference is opposite to that of RTs. The observation of PoP from one rare trial to the next has been replicated twice in our lab (unpublished data) and in no case was there a statistical difference in error rates between target color repetitions and switches. In fact, pooling data from the three experiments in which we have observed long-lasting PoP, the error rates for target repetitions (3.9%) and switches (3.5%) are near identical [$t(71) = .85$, $d = .09$, $p = .399$].

CHAPTER 5: Contextual Distinctiveness Produces Long-Lasting Priming of Pop-Out

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PREFACE

This is the final empirical chapter within this thesis. The experiments reported here build upon the work presented thus far in an attempt to address one of the key predictions of an episodic retrieval theory of priming effects in human performance. Mainly, it is shown across 4 experiments that the priming of pop-out effect is affected by non-perceptual contextual aspects of the stimulus displays. That is, long-lasting PoP is observed when task-related processes are reinstated from the influencing trial to the current trial. This result is taken as strong evidence that context-cued retrieval processes are crucial in observing the long-lasting PoP effect observed in Chapter 4; an effect best explained by reference to episodic retrieval.

Abstract

Maljkovic and Nakayama (1994; 1996; 2000) were the first to demonstrate memory influences in singleton search from one trial to the next; an effect they termed priming of pop-out (PoP). This effect was described as resulting from the implicit persistence of a transient memory trace, the influence of which could be observed for up to 5-8 subsequent trials. The short-lived nature of this priming effect has been interpreted

by some researchers as evidence for the passive decay of feature gains associated with target-defining information, and by others as a failure of memory retrieval operations due to an accumulation of interference. Thomson and Milliken (under review) showed long-term PoP (*n*-16) when 'rare' trials were composed of target/distracter colors that were distinct from the intervening 'common' trials. The present experiments tested whether long-term PoP effects are the result of contextually distinct retrieval cues. To that end, rare trials were distinguished from common trials by manipulating spatial location (Experiments 1 - 3), stimulus configuration (Experiment 3), and task (Experiment 4). Across all experiments reported here, PoP effects that survived 15 intervening trials were observed with rare search stimuli that were composed of distinct target/distracter colors or distinct tasks. Distinct stimulus location and distinct stimulus configuration failed to produce any additional measurable effects on PoP for rare trials. These results are interpreted as evidence for episodic memory retrieval processes as a primary underlying mechanism in long-term PoP.

Visual search tasks are commonly used to study the processes by which we select and attend to relevant information in our perceptual environment while ignoring irrelevant, distracting information. Despite years of empirical study using visual search tasks, the specific underlying mechanisms that allow us to search efficiently are not yet fully understood. In particular, the role of memory in visual search from one experience to the next is a particularly contentious issue. At the heart of this debate is whether visual search involves stable, abstract memory representations of particular perceptual dimensions, or alternatively context-sensitive episodic representations that include bound information about multiple stimulus dimensions. Distinguishing between these two theories in efficient search will be the primary focus of the work presented here.

Memory & Visual Search

Treisman and Gelade (1980) forwarded an account of visual search in which two discrete processes occur. First, the visual scene is analyzed in parallel, referred to as the 'pre-attentive' stage of search, in which salient areas of the scene are selected for further processing. Following pre-attentive search, attention is then drawn to the area of the visual scene with the highest salience, where more focused, 'attentive' search takes place. During this second stage, individual items are scrutinized until the target is identified and a response can be executed. While some search tasks require processing to proceed to the attentive stage for target localization, other less complex search tasks can be completed in an entirely pre-attentive manner. For example, in a conjunctive search task, participants must locate and make a response to a target amongst heterogeneous distracters, with the target defined by a particular conjunction of features, such as a blue horizontal bar amongst vertical blue bars and horizontal red bars, or a rotated 'T' amongst 'L's'.

Conjunctive search therefore (sometimes referred to as difficult search) requires that items in the display be analyzed one at a time for the presence of the features that define the target. Evidence for the serial nature of conjunctive search comes from data showing that as the number of distracting items in the display increases, search latencies also increase in a linear fashion. In contrast, in a singleton search task, participants locate and respond to a target item amongst homogeneous distracters, with the target defined along a single salient dimension, such as the odd colored item or the odd sized item. In this type of search task, salience differences in the visual scene will be sufficient for target detection and so processing need not continue to the more focused, serial, attentive stage of search. This view is supported by data demonstrating that search latencies in a singleton search task do not significantly increase as the number of distracting items in the display increase (Treisman & Gelade, 1980; Bravo & Nakayama, 1992). Some researchers have argued that the increased difficulty of conjunctive search relative to singleton search tasks opens search performance to benefits from memory for prior search experiences. In the following section some empirical evidence for memory in conjunctive search tasks is described before turning to the case of singleton search, which will be the primary focus of this article.

Given the relative complexity and serial nature of searching for a conjunctively defined target in space, Horrowitz and Wolfe (1998) hypothesized that during a search trial, memory may operate to prevent re-sampling of distracter locations during the attentive stage of search. To assess this idea, participants searched for a rotated 'T' amongst 'L's' and reported its orientation. Critically, in one condition the distracter locations remained constant (static display) and in another they randomly shifted in space every 110 ms (dynamic display). Importantly, search slopes were found to be equivalent for both the static and dynamic display conditions. This was interpreted as evidence for a lack of within trial 'tagging' of previously attended locations, and so search was argued to be an entirely 'amnesiac' process. This contention has since been called into question by research showing that search latencies can in fact differ between static and dynamic displays (Kristjansson, 2000; also see Shore & Klein, 2000 for a review), together with data showing that memory for target and distracter configurations in a conjunctive search task can affect search performance on later search trials. For example, Chun and Jiang (1998) had participants search for a rotated 'T' amongst 'L's'. In their design, a proportion of the search arrays were repeated in each block within an experimental session. Search times were significantly reduced for repeated displays relative to novel displays, despite an absence of explicit memory for repeated displays. This effect was termed contextual cueing and is argued to reflect the automatic retrieval of bound episodic memory representations during conjunctive search.

While there is general consensus among researchers that conjunctive search results in the creation and retrieval of memory representations that are likely episodic in nature (see Chun & Phelps, 1999), the role of memory in efficient (or pop-out) search is not yet fully understood. In a series of experiments, Maljkovic and Nakayama (1994; 1996; 2000) were the first to demonstrate the role of memory in singleton search. In their experiments, participants searched for an odd-colored diamond amongst two homogeneous distracters and indicated whether it was truncated on the left or right. Performance was analyzed on the current trial as a function of the repetition or alternation of the target-defining feature from the previous trial. Importantly, they found that search times were faster for repeated target colors compared to switches, an effect they termed priming of pop-out (PoP). PoP, it was argued, reflects the operation of a short-term, implicit memory trace that contains target-defining feature information. This memory trace was shown to affect performance for 5-8 subsequent trials (Maljkovic & Nakayama, 1994, Experiment 5) and was argued to affect performance without awareness (Maljkovic & Nakayama, 2000). This conceptualization of the memory mechanism underlying PoP has been somewhat revised to account for data showing that salient but task-irrelevant information seems to produce priming effects from one trial to the next, albeit to a lesser extent than target-defining information. For example, Huang, Holcombe and Pashler (2004) showed that when the color of an odd-sized singleton repeated from one trial to the next, search times were faster than when the irrelevant color dimension switched. Similarly, Kristjansson (2006) demonstrated that the task-irrelevant color of a singleton target defined by either orientation or spatial frequency produced priming from one trial to the next.

In summary, theories of memory in singleton priming have been adapted to include both target-relevant and irrelevant perceptual information. These theories generally fall into two categories: activation/suppression of low-level features from one trial to the next versus bound episodic representations that are automatically created and retrieved on each search experience. The central tenets of, and empirical evidence for, each of these competing theories will be discussed in turn.

Activation/Suppression Accounts of PoP

Activation/suppression theories of PoP are broadly consistent with the original conceptualization of PoP as resulting from the persistence of an activated memory trace for target-defining feature information. Although the current instantiation of this idea also allows for target-irrelevant information to guide search, the basic principles of such a theory remain largely unchanged. In general, activation/suppression accounts of PoP (sometimes referred to simply as feature priming accounts) posit that the attended features of targets and distracters within a singleton search array result in activation or suppression of abstract representations that persist passively in time and begin to decay (back towards some baseline level of activation) post-response. Evidence for such accounts can be found in the original Maljkovic and Nakayama (1994) study (Experiment 7), in which they demonstrated a cumulative benefit to search speed for multiple repetitions of the target feature. This result has been taken to imply that each presentation of a given target color further raises the activation level for that feature, allowing attention to be drawn to that feature even faster. This cumulative repetition benefit has since been replicated by a host of other researchers (Hillstrom, 2000; Becker, 2007; Geyer & Muller, 2009; Kristjansson, Sigurjonsdottir & Driver, 2010) and is argued to occur together with suppression of the distracter feature on each search trial (Goolsby & Suzuki, 2001; Lamy, Antebi, Aviani & Carmel, 2008). Thus activation/suppression accounts of PoP posit that attended, low-level perceptual information results in activation or suppression of abstract feature representations that carry forward in time.

Another key principle of activation/suppression accounts of PoP is that activation of feature representations (referred to by some researchers as ‘weights’ or attentional ‘gains’; see Lee, Mozer & Vecera, 2009) is set independently for each feature dimension. For example, Lamy, et al. (2008) had participants search for a color singleton on each trial, in which the colors of the target and distracters were randomly selected from a four-color set. Using this design, PoP was assessed for conditions in which both target and distracter colors repeated or switched from one trial to the next, or one of either target or distracter color could repeat from one trial to the next while the other switched. The key finding was that target color repetitions speeded responding regardless of whether distracter color repeated or alternated and that distracter color repetition speeded responding regardless of target color alternation or repetition, which led to the conclusion that target activation and distracter inhibition levels are set independently on each trial. Similarly, Lee, et al. (2009) found that search times for locating a color singleton were expedited when the color of the target matched that of an irrelevant object that was inserted between search displays. This result was taken as evidence for automatic and independent adjustments in attentional gains associated with low-level perceptual features that summate onto a 'master' map that guides attention to areas in space that share those same features on subsequent displays (a similar account has been forwarded by Wolfe, 1989; see also Wolfe, Butcher, Lee & Hyle, 2003).

Taken together, activation/suppression accounts of PoP are characterized by at least four distinct properties. First, memory traces that produce PoP are restricted to low-level perceptual information such as color or form. Second, activation states in abstract representations that correspond to these perceptual dimensions are set independently. Third, these activation states are set on one trial and carry forward in time such that they are measured on subsequent trials. Finally, activation/suppression states (or attentional gains) decay passively across time.

Episodic Retrieval Theories of PoP

A somewhat different account of priming effects in singleton search has recently been forwarded that postulates the creation of bound episodic memory representations on each search experience that are then retrieved implicitly and automatically upon onset of subsequent displays (see Hillstrom, 2000; Huang et al., 2004; Thomson & Milliken, 2011). To the extent that the properties of current perception match the contents of the retrieved episode, performance is facilitated, and conversely, to the extent that there is a mismatch between one or more aspects of prior experience and current perception, performance is slowed. This idea generally fits with the transfer appropriate processing principle often used to interpret performance in explicit remembering tasks (see Morris, Bransford & Franks, 1977). Although the idea of episodic memories being created and retrieved implicitly in the context of a performance task is not in itself new, its application to priming effects in singleton search is quite recent. This general idea will briefly be discussed before turning to the evidence for episodic influences as a primary mechanism driving PoP.

Logan (1988) forwarded an account of episodic retrieval operations in the context of tasks that have no requirement for participants to remember. According to this framework, each experience we have with perception and action results in the automatic creation of an integrated memory representation referred to as an instance. As experience with a task accumulates, so do the number of instances and hence, the probability that a prior instance can be quickly retrieved also increases. When there are enough instances stored in memory, it becomes easier to retrieve perceptual and response information than to complete the task algorithmically. These instances have been argued to drive both skill acquisition as well as priming effects that are observed in performance tasks (Logan, 1988; 1990).

Kahneman, Treisman and Gibbs (1992) found evidence for the implicit recruitment of instance-like representations in a simple letter identification task. In their task, participants viewed two or more letters that appeared in marked locations in a preview display. In a probe display, participants identified a single letter that appeared previously in the preview display. Importantly, they found that identification times were faster for letters that appeared in the same marked location from prime to probe than when location switched. They argued that an integrated representation of location and identity information were encoded in memory during the prime display and automatically recruited upon onset of the probe display. They referred to these memories as 'object files'. Hommel (1998) expanded on the concept of object files to include action related information. In his experiments, it was shown that performance was expedited when both perceptual and action/response information matched from prime to probe displays, indicating that perception and action are bound together in memory in what he referred to as an 'event file' (also see Hommel, 2004).

Episodic memory representations can therefore be thought of as a viable source of priming effects in human perception and performance. Importantly, this episodic memory account of priming effects differs markedly from activation/suppression accounts in a number of ways. First, both perceptual and non-perceptual information are encoded into memory episodes. Second, representations of multiple stimulus attributes are bound, or integrated in memory, rather than represented independently. Third, activated representations do not persist in time from one experience to the next, but instead are retrieved from memory during current perception and action. Finally, memory episodes do not decay passively across time, but instead their availability is reduced as interference from other episodes accumulates. Although episodic memory influences have been demonstrated in other sub-domains of the attention and performance literature (e.g., negative priming - Neill, Valdes, Terry & Gorfein, 1992; conflict adaptation -Spape & Hommel, 2008; inhibition of return - Wilson, Castel & Pratt, 2006), episodic retrieval accounts of PoP are relatively undeveloped.

Hillstrom (2000) was the first to posit episodic retrieval as an explanatory tool for understanding priming effects in singleton search tasks. In her experiments, interactions were observed between the target-defining feature and the reported feature from trial *n*-1 to trial *n*. In other words, the effects on performance for repetition of one feature depended on whether the other feature also repeated, suggesting that information is integrated in memory, not represented independently as in an activation/suppression framework. Hillstrom concluded that bound episodic memory representations may be stored temporarily in working memory on one trial, and subsequently recruited in the presence of a 'crude' pre-attentive map of the current display. Similar findings have also been reported by Huang et al. (2004) who had subjects locate an odd-sized bar and report its orientation. Interestingly, they observed that priming effects for the target-defining feature (size) interacted with a repetition/alternation of a task-irrelevant feature (color) from trial *n*-1 to trial *n* (i.e. partial match effects, see Hommel, 1998). Again, this result was taken as evidence for bound, or integrated memory representations driving PoP, as in an episodic retrieval framework. Finally, Thomson and Milliken (2011) demonstrated that PoP effects for odd-colored and odd-shaped singletons were significantly reduced when higher order task demands switched from one trial to the next (i.e., switching from a left/right to a top/bottom decision about a gap in the target item), suggesting that non-perceptual, but task-relevant, information also gets represented in memory in a bound manner. Again, such a result was taken as evidence for the role of episodic representations guiding singleton search.

Taken together, there is convincing evidence that the memory mechanisms driving PoP may be bound or integrated representations that include both perceptual and non-perceptual information. Although these findings pose problems for a strict activation/suppression account of PoP, key predictions of the episodic retrieval framework have yet to be tested. Of particular interest here is the fact that the underlying basis of the short-lived nature of PoP has not been studied in much detail. Do PoP effects last only 5-8 trials because of the passive decay of abstract weights associated with independently represented features? Or might this effect result from an accumulation of interference from intervening items? This issue will be the empirical focus of the experiments that follow.

The Present Study

The primary purpose of the work reported here is to assess whether the short-lived nature of the PoP effect is due to interference from intervening items that affect memory retrieval processes on the one hand, or feature gains associated with target-defining information on the other hand. As mentioned earlier, PoP has been shown to exert its influence for up to 5-8 subsequent trials (Maljkovic & Nakayama, 1994, Experiment 5) at the most (Geyer, Muller & Krummenacher, 2007 found PoP for location that lasted only four trials, Hillstrom, 2000 found PoP for color that lasted only three trials). The transient nature of PoP has been taken as evidence for the passive decay of abstract feature activation/suppression states (see Lee, et al., 2009). An alternative interpretation of the seemingly transient nature of PoP is that as the number of intervening items between the current trial and the influencing trial increases, the probability that the representation corresponding to the influencing trial will be uniquely retrieved decreases. It has so far been impossible to differentiate between passive decay and interference as the mechanism of 'forgetting' in PoP since time and intervening items have always been confounded. As such, the short-lived nature of the PoP effect could easily fit into either an activation/suppression account or an episodic retrieval account of the priming of pop-out effect.

Under an episodic retrieval framework of priming effects in human performance, the probability that a given prior episode will be retrieved is largely based on how good the match is between the contents of that episode and current perception (Morris, Bransford & Franks, 1977; Logan, 1988; Hommel, 1998). To the extent that search displays share many, or all perceptual attributes (as in standard singleton search tasks), intervening items will quickly reduce the probability of retrieval of a given prior episode. On the other hand, to the extent that some aspect of current perception and action uniquely matches a prior experience, the episode corresponding to that experience should be uniquely retrieved, regardless of the number of intervening experiences. Initial evidence for this latter contention was observed by Thomson and Milliken (under review) in which long-term PoP effects (*n*-16) were observed when the dimension that defined the target (color) was used to distinguish current and influencing trials from intervening search experiences. The present series of experiments has participants locate and make a discrimination judgment to an odd-colored item amongst two homogeneous distracters. Importantly, two different types of search arrays are presented in each experiment. One class of search array (referred to as 'common' trials) appeared in runs of 15, while the other appears only once every 16 trials (referred to as 'rare' trials). The primary goal of these experiments is to examine whether dimensions other than those that define the pop-out target can function as contextually distinct retrieval cues. Across four experiments we vary the contextual distinctiveness of the rare trials with respect to the common trials in an effort to reduce interference from the intervening common trials. In Experiment 1 we present the rare trials in spatially distinct locations on the computer screen, in Experiment 2 we present the rare trials both in distinct locations and in distinct target/distracter colors, in Experiment 3 we present the rare trials in a distinct location, with distinct colors and a distinct target/distracter configuration, and finally in Experiment 4, we distinguish rare trials from common trials based on the task that is to be performed on the target. If the short-lived nature of PoP is due to passive decay of abstract activation/suppression of feature representations, then the PoP effect should not be observed when measured from rare trial to rare trial (across 15 intervening common trials). If however, an accumulation of interference from intervening items reduces the probability of retrieval of a preceding search experience, then building in contextually distinct properties of the rare displays should provide unique retrieval cues and therefore PoP should be observed from rare trial to rare trial, even when contextual distinctiveness is manipulated along a dimension that is not tied to the target-defining feature (color).

Experiment 1

The purpose of Experiment 1 is to assess whether presenting rare search arrays in spatially distinct contexts will be sufficient to produce the long-lasting PoP effects that were observed in our previous work. The logic is as follows: if stimulus onset triggers the retrieval of a recent memory episode depending on the match between current perception and a recent experience, then spatial location should serve as context to cue retrieval of the most recent search experience within that context. In the case of rare trials, the most recent experience with the rare spatial location would have occurred 16 trials ago, and so recruitment of the *n*-16 episode should facilitate target localization for target repetitions and slow localization for target alternations from one rare trial to the next. If however, the memory representation that drives PoP can only be recruited by a match along the target-defining dimension (color) then no significant PoP will be observed from one rare trial to the next.

Method

Participants. 20 undergraduate students from McMaster University (2 male, 18 female, mean age = 20.3 years) participated in exchange for either course credit or $10 CAD for one hour of participation. All participants had normal or corrected to normal vision.

Apparatus/Stimuli. Search arrays were presented using Presentation software on a Dell 15 inch CRT monitor connected to a Dell PC. Each search array contained three squares that subtended a vertical and horizontal visual angle of 1.1 degrees. Each square contained a gap in either the left or right side that subtended a visual angle of 0.6 degrees vertically. Each search array was arranged in an equilateral triangle with a fixation cross at the center, which subtended a vertical and horizontal visual angle of 0.6 degrees. Each array contained two homogeneous distracter items and one target item (i.e., if the target item was randomly assigned to be red on a given trial, the distracters were presented in green). Common trials were presented in one location on the computer screen (centered either in the top or bottom half), while rare trials were presented in the opposite location. This assignment of screen location to common and rare trials was counter-balanced across participants.

Procedure. Participants were seated approximately 57 cm from the computer screen and were instructed that on each trial they would see three squares arranged in a triangular formation around a central fixation cross. They were asked to locate the odd-colored square in each display and to indicate whether it had a gap in the left or right side as quickly and accurately as possible. Participants indicated a 'left' response by hitting the 'z' key with their left index finger and indicated a 'right' response by hitting the '/' key with their right index finger.

Each stimulus array was preceded by a fixation cross that appeared 300 ms before the search array and remained on the screen until a response was made, at which point the stimulus array, together with the fixation cross, disappeared. The screen then remained blank for 500 ms until the fixation-cross appeared again to signal the next trial. This resulted in an 800 ms response-to-stimulus interval between search arrays. Participants completed 15 search trials in one screen location and then completed one search trial in the opposite location (for example if common search arrays appeared in the bottom half of the computer screen, then rare search trials appeared in the top half of the screen). This sequence was repeated 100 times for a total of 1600 trials (1500 common, 100 rare).

The first eight trials in the experiment were used for practice and instructional purposes, resulting in 1592 experimental trials. Participants were given the opportunity to take a break every 200 trials and the experiment resumed whenever the participant pressed the space bar to initiate the next block. The trial sequence is presented in Figure 1a.

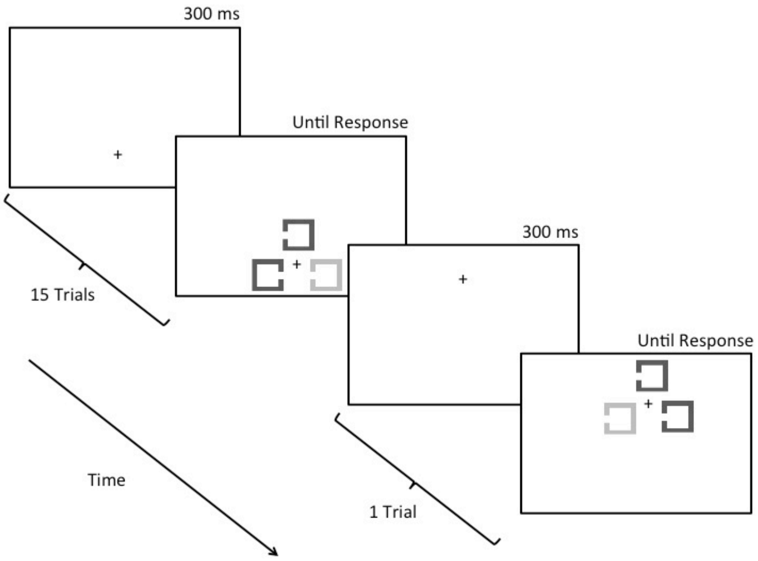

Figure 1a. A depiction of the procedure used in Experiment 1, in which participants locate and respond to the odd-colored square in each display (actual display elements were presented in red and green). Stimulus displays remained on the screen until a response was executed and then after a 500 ms blank interval, the fixation cross for the next search array appeared. Participants performed 15 trials in one screen location (referred to as 'common') followed by one trial in the opposite screen location (referred to as 'rare').

Results

Only trials on which correct responses were made were submitted to the response time analysis. As each experimental condition is contingent on the nature of the previous trial type, response times and errors for trials immediately following an error response were also excluded from analysis. All remaining RTs were submitted to an outlier procedure that excluded RTs based on outlier criteria that varied as a function of cell size (see Van Selst & Jolicoeur, 1994). Separate cells of observations were created using RTs for common trials as a function of whether the target color repeated or switched in relation to the immediately preceding trial (*n*-1), to the trial just before the immediately preceding trial (*n*-2), and so on, back to trial *n*-9. Note that this analytic strategy implied that any particular response time could contribute to the mean RT for multiple preceding trial types (e.g., trial *n* RT might contribute both to the target repeat mean RT for the *n*-1 preceding trial type, but to either the target repeat or target switch mean RT for the *n*-2 preceding trial type). Similarly, separate cells of observations were created using RTs for rare trials as a function of whether the target color repeated or switched from the immediately preceding rare trial (*n*-16) as well as prior influencing rare trials (*n*-32 and *n*-48). Overall, the outlier analysis eliminated 2.6 % of the observations. Mean RTs were then computed from the remaining observations. These mean RTs are shown in Figure 1b. Error rates were computed in a similar manner for first-order sequence effects (*n*-1 for common trials, *n*-16 for rare trials). A summary of error rates for target color repetitions and switches on common trials as a function of the immediately preceding common trial (*n*-1), and on rare trials as a function of the immediately preceding rare trial (*n*-16), are shown in Table 1.

Our analyses centered on three issues. First, we compared performance for the common and rare trials, simply to evaluate whether this factor affected performance overall. Second, we examined performance on common trials, excluding those trials in which the preceding trial was a rare trial. Our objective here was to evaluate whether the data replicate the results reported in prior studies that have not included rare trials. Third, and most important, we examined performance on rare trials to evaluate whether PoP effects can occur relative to other rare trials that happened 16 trials prior. This treatment of the data for both response times and error rates will be identical in all subsequent experiments.

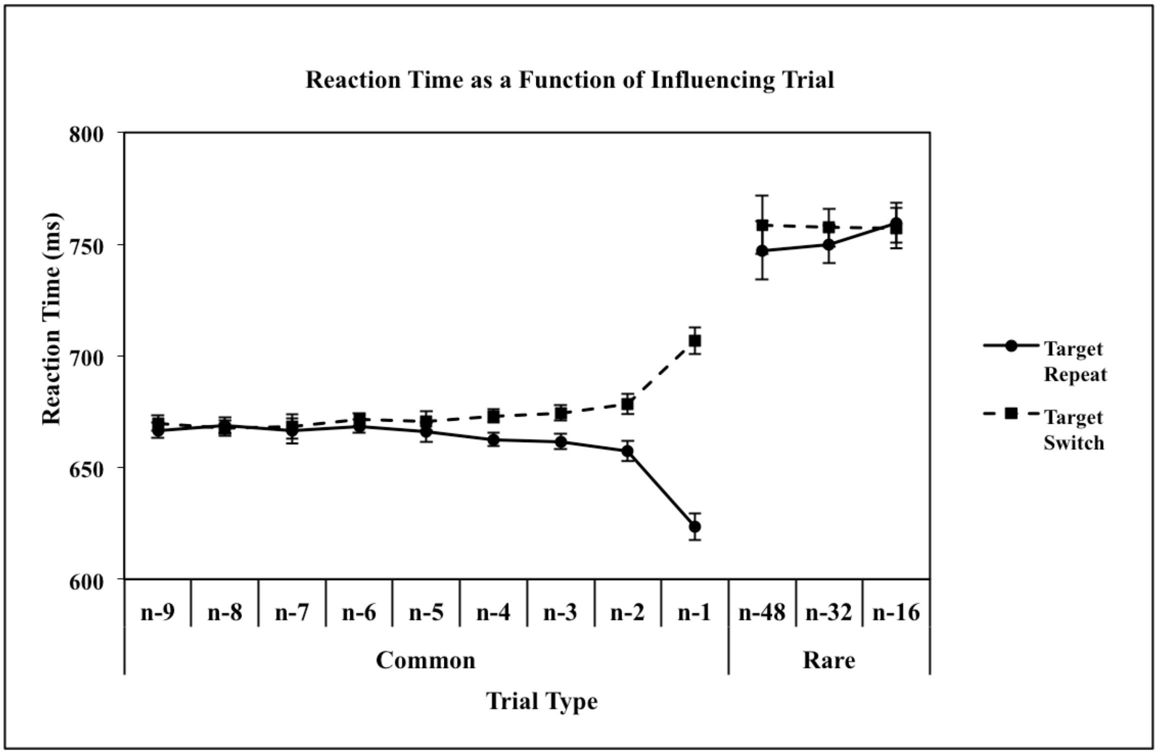

Figure 1b. Reaction time is shown for target repetitions and alternations as a function of the prior influencing trial for both common and rare trial types. Error bars represent standard errors of the mean of the priming effects (target switch – target repeat).

Response times. There was a significant effect of trial type, with reaction times being faster for common trials (665 ms) than for rare trials (758 ms), *t (*19) = 10.23, *p* < .0001, *d* = .67.

In order to assess the magnitude of the PoP effect on the current trial as a function of the previous influencing trials, planned comparisons were conducted that compared target repetitions and alternations. For the common trials, these analyses indicated significant PoP effects on the current trial as a function of the following influencing trials: *n*-1 (83 ms), $t\,(19) = 14.79$, $p < .0001$, $d = .66$, *n*-2 (21 ms), $t\,(19) = 4.98$, $p < .0001$, $d = .16$, *n*-3 (13 ms), $t\,(19) = 3.99$, $p = .0008$, $d = .10$, *n*-4 (10 ms), $t\,(19) = 3.87$, $p = .001$, $d = .08$, but no significant PoP effect for the following trials: *n*-5 (5 ms), *n*-6 (3 ms), *n*-7 (2 ms), *n*-8 (-1 ms), *n*-9 (3 ms).

Of primary interest here, is whether PoP could be observed when the current and influencing trial were of the rare trial type. For the rare trials planned comparisons revealed no significant PoP effect at *n*-16 (-2 ms), *n*-32 (8 ms) or *n*-48 (11 ms).

Table 1. Mean error percentages (M) and standard deviations (SD) in Experiment 1 for common and rare trial types as a function of target (repeat/switch) on trial *n* as a function of the previous trial (*n*-1 for common trials, *n*-16 for rare trials).

	Trial Type			
	Common		Rare	
	M	SD	M	SD
Target Repeat	4.3	(2.5)	4.6	(5.1)
Target Switch	6.9	(3.6)	3.3	(2.2)

Error rates. The analysis of error rates revealed that significantly more errors were committed on common trials (5.6 %) than on rare trials (3.9 %), $t\,(19) = 2.44$, $p = .025$, $d = .52$, suggesting perhaps that the onset of a rare trial led participants to respond both more slowly and accurately overall. In the analysis of the common trials, more errors were committed on target switches from trial n-1 to trial n (6.9%) than target repetitions from trial n-1 to trial n (4.3 %), $t(19) = 6.38$, $p < .0001$, $d = .83$. In the analysis of the rare trials, there was no significant difference in error rates for target repetitions (4.6 %) and switches (3.3 %) from trial n-16 to trial n.

Discussion

The purpose of Experiment 1 was to assess whether long lasting priming of pop-out could be measured from one rare trial to the next when those trials were associated with distinct locations in space. It was demonstrated that PoP effects for the common trials could be measured up to four items back, which fits well with previous work; PoP for color usually lasts from three to eight trials. Of primary interest here was whether significant PoP would be observed from rare trial to rare trial (*n*-16 to *n*). The results were clear, in that no priming effect emerged for rare trials. This result has two possible interpretations: (1) PoP is driven by activation/suppression states of feature representations that do not persist forward in time more than a few trials when the intervening trials require re-modulation of those representations, or (2) spatial location did not serve as a useful contextual cue with which to retrieve the most recent episode in that location. If this latter interpretation is correct, it may be that spatial location of the search array was not encoded into the memory episodes that were laid down on each search trial. This may have occurred because spatial location of the array itself is not relevant to the task of locating an odd colored item. Indeed, some prior work has shown that perceptual features of a search array receive attentional prioritization in accord with task-relevance, and that the strength of a feature representation in episodic memory is directly related to the degree of attention that feature received at encoding (see Hommel, 2004). To address this potential interpretation, Experiment 2 included an additional contextual cue for rare trials that was directly relevant to the task itself.

Experiment 2

The absence of a long-term PoP effect in Experiment 1, together with our prior study demonstrating a long-term PoP effect when distinct colors were used on common and rare trials, suggests that color but not location serves as an effective contextual cue for measuring long-term PoP. However, this conclusion requires a replication of our earlier study that used color as a contextual cue. To that end, we combined the distinguishing rare trial property of Experiment 1 (location) with color, with the idea that the conjunction of unique color and location information on rare trials should certainly produce a long-term PoP effect. Indeed, it seemed possible that the conjunction of a distinct location and distinct target/distractor colors on rare trials might profoundly reduce interference from intervening common trials, to the point that the PoP effect for rare trials might be larger than that observed in our prior study with color alone as the contextual cue.

Method

Participants. 24 undergraduate students from McMaster University (3 male, 21 female, mean age = 18.96 years) participated in exchange for either course credit or $10 CAD for one hour of participation. All participants had normal or corrected to normal vision.

Apparatus and stimuli. All apparatus and stimuli were the same as those used in Experiment 1, with the following exceptions: target and distracter colors were red and green for one trial type (e.g., rare) and were blue and yellow for the other trial type (e.g., common), with the assignment of colors to trial types counter balanced between participants.

Procedure. The procedure used in Experiment 2 was identical to that used in Experiment 1, with no exceptions.

Results

The outlier elimination procedure removed 2.7 % of observations. Mean response times and corresponding error rates are shown in Table 2. Mean response times for target repetitions and switches as a function of influencing trial are shown in Figure 2.

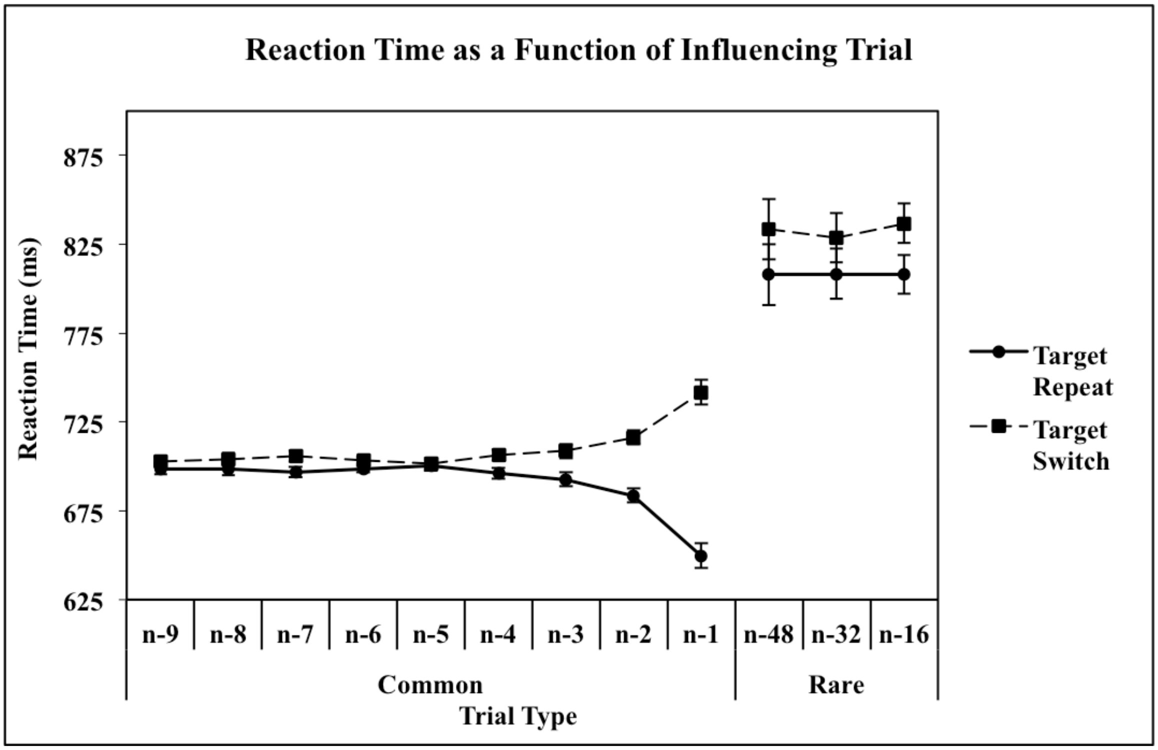

Figure 2. Reaction time is shown for target repetitions and alternations as a function of the prior influencing trial for both common and rare trial types. Error bars represent standard errors of the mean of the priming effects (target switch – target repeat).

Response times. There was a significant effect of trial type, *t (*23) = 6.66, *p* < .0001, *d* = 1.08, with reaction times being faster for common trials (696 ms) than for rare trials (822 ms).

In order to assess the magnitude of the PoP effect on the current trial as a function of the previous influencing trials, planned comparisons were conducted that compared target repetitions and alternations. For the common trials, these analyses indicated significant PoP effects on the current trial as a function of the following influencing trials: *n*-1 (92 ms), *t (*23) = 13.08, *p* < .0001, *d* = 1.03, *n*-2 (33 ms), *t (*23) = 8.75, *p* < .0001, *d* = .36, *n*-3 (16 ms), *t (*23) = 4.62, *p* < .0001, *d* = .18, *n*-4 (10 ms), *t (*23) = 3.11, *p* = .0049, *d* = .12, *n*-6 (5 ms), *t (*23) = 2.09, *p* = .048, *d* = .05, *n*-7 (9 ms), *t (*23) = 3.08, *p* = .0053, *d* = .10, and no significant PoP effects as a function of the following influencing trials: *n*-5 (1 ms), *n*-8 (5 ms), *n*-9 (4 ms).

Most importantly, for the rare trials these analyses revealed a significant PoP effect at *n*-16 (29 ms), *t (*23) = 2.67, *p* = .014, *d* = .19, but not at *n*-32 (21 ms) or *n*-48 (26 ms).

Table 2. Mean error rates percentages (M) and standard deviations (SD) in Experiment 2 for common and rare trial types as a function of target (repeat/switch) on trial *n* as a function of the previous trial (*n*-1 for common trials, *n*-16 for rare trials).

	Trial Type			
	Common		Rare	
	M	(SD)	M	(SD)
Target Repeat	4.0	(2.4)	2.9	(2.8)
Target Switch	5.5	(3.1)	3.1	(2.9)

Error rates. The analysis of error rates revealed that significantly more errors were committed on common trials (4.7 %) than on rare trials (3.0 %), *t (*23) = 3.52, *p* = .0018, *d* = 0.66, suggesting perhaps that the onset of a rare trial led participants to respond both more slowly and accurately overall. In the analysis of the common trials, more errors were committed on target switches (5.5 %) than target repetitions (4.0 %), *t (*23) = 4.51, *p* = .0002, *d* = .53, from trial n-1 to trial n. In the analysis of the rare trials, there was no significant difference in error rates for target repetitions (2.9 %) and switches (3.1 %) from trial *n*-16 to trial n.

Discussion

The primary purpose of Experiment 2 was to assess whether presenting search arrays in unique contexts, defined by spatial location and target/distracter colors, would yield priming of pop-out effects that could be measured from one rare trial to the next (*n*-16 to *n*). As context for this result, we note that PoP effects for the common trials were observed up to *n*-7 but not beyond. In this light, the key result here is the significant PoP effect for rare trials where the influencing trial was trial *n*-16. This result replicates a result we reported in an earlier study (Thomson & Milliken, under review) in which color alone served as the unique contextual cue on rare trials. It is interesting to note that the magnitude of the effect in the present experiment was very similar to that observed in our prior study (31 ms compared to 29 ms), suggesting that the location contributes little on its own (Experiment 1) or in combination with target/distractor color (Experiment 2) to the long-term PoP effect of interest here. In the following experiment, we added a third unique contextual dimension to the rare trials to examine again whether magnification of the long-term PoP effect beyond that observed with color as the lone unique contextual cue is possible. Specifically, we added target-distracter configuration to the list of unique contextual dimensions that differentiated common and rare trials.

Experiment 3

The purpose of Experiment 3 was to assess whether adding target/distracter configuration as an additional contextual dimension for rare trials would produce larger PoP effects from rare trial to rare trial than when color alone served as a contextual cue. As in Experiment 3, the idea is that if the distinctiveness of rare trials with respect to common trials serves to cue retrieval of the most recent experience within that context, then increasing this distinctiveness should further increase the probability of retrieving the most recent (*n*-16) rare trial episode, and consequently increase the long-term PoP effect.

Method

Participants. 24 undergraduate students from McMaster University (6 male, 18 female, mean age = 22.5 years) participated in exchange for either course credit or $10 `CAD for one hour of participation. All participants had normal or corrected to normal vision.

Apparatus and Stimuli. All apparatus and stimuli were identical to that used in Experiment 2, with one exception: for one of the trial types (rare or common) the configuration of targets and distracters was an inverted equilateral triangle, and for the other trial type it was a right-side-up triangle (as in Experiments 1 and 2). This assignment of configuration to trial type was counter balanced between participants.

Procedure. The procedure was identical to that used in Experiments 1 and 2. An illustration of the procedure can be found in Figure 3a.

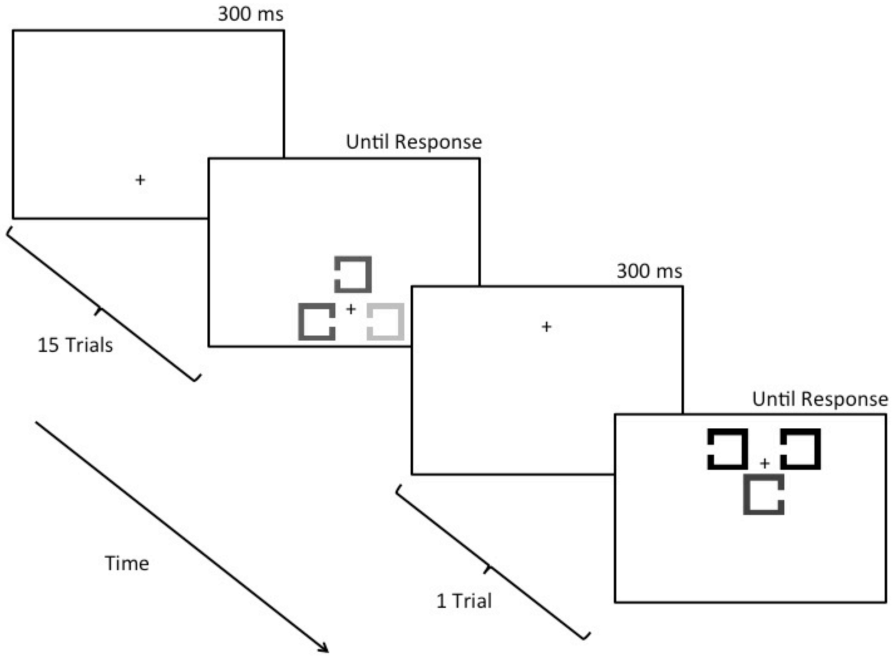

Figure 3a. A depiction of the procedure used in Experiment 3, in which participants locate and respond to the odd-colored square in each display. Stimulus displays remained on the screen until a response was executed and then after a 500 ms blank interval, the fixation cross for the next search array appeared. Participants performed 15 trials in one location (top or bottom) and in one target/distracter color combination (red/green or blue/yellow) followed by one trial in the opposite location with opposite configuration and target/distracter colors.

Results

The outlier elimination procedure removed 2.4 % of the observations. Mean response times and corresponding error rates are shown in Table 3. Mean response times for target repetitions and switches as a function of influencing trial are shown in Figure 3b.

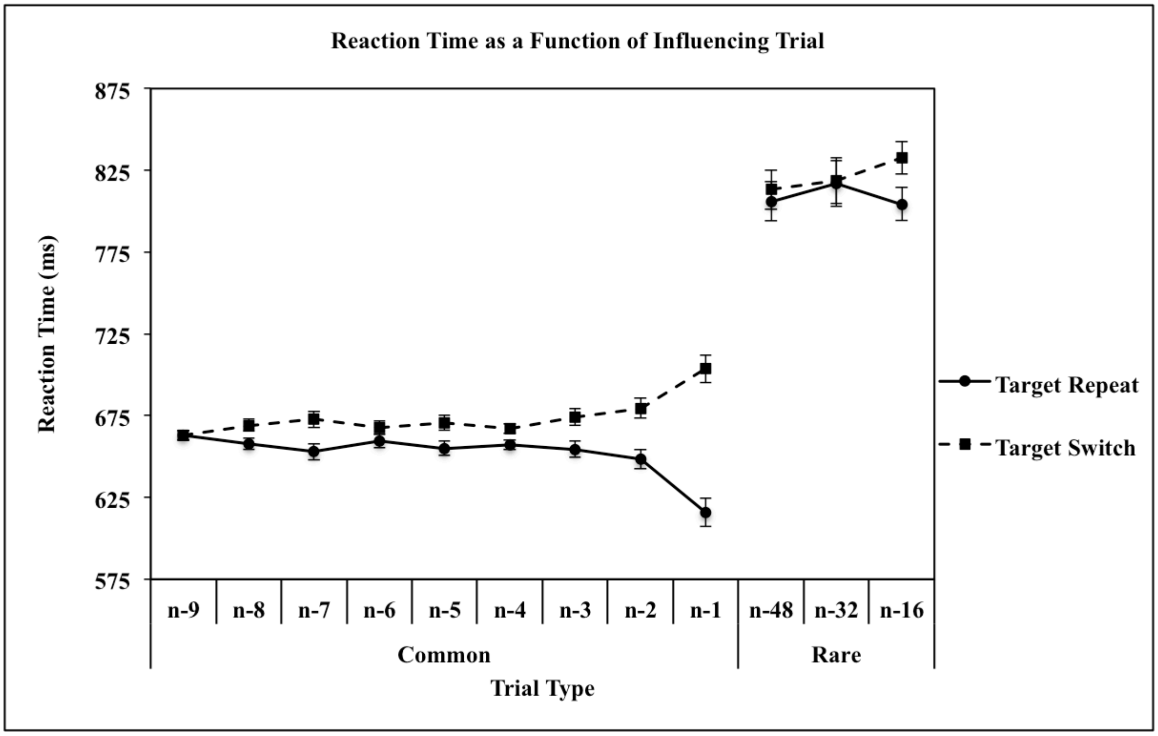

Figure 3b. Reaction time is shown for target repetitions and alternations as a function of the prior influencing trial for both common and rare trial types. Error bars represent standard errors of the mean of the priming effects (target switch – target repeat).

Response times. There was a significant effect of trial type, *t (*23) = 9.42 , *p* < .0001, *d* = 1.31, with reaction times being faster for common trials (660 ms) than for rare trials (819 ms).

In order to assess the magnitude of the PoP effect on the current trial as a function of the previous influencing trials, planned comparisons were conducted that compared target repetitions and alternations. For the common trials, these analyses indicated significant PoP effects on the current trial as a function of the following influencing trials: n-1 (88 ms), *t (*23) = 10.8, *p* < .0001, *d* = .92, n-2 (31 ms), *t (*23) = 5.39, p < .0001, *d* = .31, n-3 (20 ms), *t (*23) = 4.15, *p* = .0004, *d* = .20, n-4 (10 ms), *t (*23) = 3.37, *p*

= .0027, *d* = .10, n-5 (16 ms), *t (*23) = 3.66, *p* = .0013, *d* = .16, n-6 (8 ms), *t (*23) = 2.32, *p* = .0297, *d* = .09, n-7 (20 ms), *t (*23) = 4.12, *p* = .0004, *d* = .20, n-8 (11 ms), *t (*23) = 3.42, *p* = .0023, *d* = .12. No significant PoP effect was observed on trial n as a function of trial n-9 (0 ms).

Of primary interest, for the rare trials these analyses revealed a significant PoP effect at n-16 (28 ms), *t (*23) = 2.83, *p* = .0095, *d* = .19, but not at n-32 (2 ms) or n-48 (7 ms).

Table 3. Mean error rates percentages (M) and standard deviations (SD) in Experiment 3 for common and rare trial types as a function of target (repeat/switch) on trial *n* as a function of the previous trial (*n*-1 for common trials, *n*-16 for rare trials).

	Trial Type			
	Common		Rare	
	M	(SD)	M	(SD)
Target Repeat	4.6	(2.8)	5.1	(6.1)
Target Switch	6.6	(4.2)	4.2	(4.3)

Error rates. The analysis of error rates revealed no significant difference in error rates between common trials (5.6 %) and rare trials (4.7 %). In the analysis of the common trials, more errors were committed on target switches (6.6 %) than target repetitions (4.6 %), *t (*23) = 4.20, *p* = .0003, *d* = .58 from trial n-1 to trial n.. In the analysis of the rare trials, there was no significant difference in error rates for target repetitions (5.1 %) and switches (4.2 %) from trial *n*-16 to trial n.

Discussion

The purpose of Experiment 3 was to examine whether the long-lasting PoP effect measured in Experiment 2 might be magnified by introducing an additional distinctive contextual cue on rare trials. Importantly, we replicated the finding of PoP from one rare trial to the next, again suggesting that the memory representations that drive PoP may not be as short-lived as has been previously argued. The magnitude of this effect however, was nearly identical to that observed in Experiment 2 (28 ms compared with 29 ms), suggesting again that unique configurations added nothing to the long-term PoP effects that can be observed when using unique target/distractor colors as contextual cues.

Taken together, the results of the experiments reported so far suggest that long-term PoP can be observed to the extent that the target-defining dimension (color) differs between common and rare trial types. Target-irrelevant dimensions such as search array location and configuration did not produce any additional measureable effects on PoP from one rare trial to the next. These findings have two possible interpretations with respect to the nature of the memory mechanism underlying PoP. First, target feature activation/suppression for rare trial target/distractor colors may decay at a particularly slow rate in our experiments because intervening common trials do not involve those same target/distractor colors (except for Experiment 1 in which no long-term PoP was observed). In effect, this interpretation assumes that trials that share target/distractor colors can result in "re-modulation" of the activation states of target/distractor colors from trial to trial, which in turn makes it difficult to measure PoP effects over many intervening trials. Second, because target/distracter color is highly relevant to the task (whereas search array location and configuration are not), color may be the only dimension that receives enough attention to be encoded into a memory episode, and is therefore the only dimension that can serve as an effective retrieval cue for the most recent rare trial episode. The purpose of Experiment 4 therefore, was to assess whether a task-relevant, but non-target-defining attribute of the search arrays, can serve to differentiate common and rare trials, and thus produce long-lasting PoP. Specifically, we manipulated the task that was performed on the target for common and rare trial types.

Experiment 4

The long-lasting PoP effects observed thus far have all occurred with rare trials that were distinguished from the intervening common trials by presenting them in different target/distracter colors. Although this result certainly challenges the notion that PoP effects survive only 5-8 intervening trials, an activation/suppression account of PoP effects might be able to accommodate such a result. In particular, it could be argued that activation of the target color on a rare trial decays slowly during the intervening presentation of common trials precisely because the common trials are composed of different colors. The presentation of different target/distractor colors for the common trials would ensure that the target/distractor colors from the rare trials were not 're-modulated' in any way during presentation of common trials, allowing activation of the rare target/distractor colors to decay slowly and passively, and yet not entirely after an interval of 16 trials. The key point to note here is that long-term PoP effects measured with unique colors on rare trials could conceivably be accommodated by an activation/suppression account of PoP, and does not require an episodic retrieval interpretation.

The purpose of Experiment 4 was to examine whether the long-lasting PoP effects observed in Experiments 2 and 3 could be demonstrated using a contextual distinctiveness manipulation that is not tied to the target-defining dimension of color. To that end, we manipulated the task that participants performed on common and rare trial types. Thomson and Milliken (2011, Experiment 4) demonstrated that PoP effects are significantly diminished from one trial to the next when the task switches compared to when it repeats, suggesting that top-down knowledge of the task is bound to memory episodes and affects performance from one trial to the next. Task was manipulated in the present experiment in the following way: for common trials, participants performed a 'top'/'bottom' discrimination for a gap in the odd-colored target, whereas for rare trials, participants performed a 'left'/'right' discrimination for a second gap in the odd-colored target. Importantly, target/distracter colors were identical for both common and rare search arrays, meaning that any PoP observed from one rare trial to the next can not be explained by slow decaying feature gains for target-defining features.

Method

Participants. 28 undergraduate students from McMaster University (5 male, 23 female, mean age = 18.4 years) participated in exchange for course credit. All participants had normal or corrected to normal vision.

Apparatus and Stimuli. All apparatus and stimuli were identical to that used in Experiment 2, with the following exceptions: target and distracter elements had a gap in either the left or right and in either the top or bottom, in order to allow two different discrimination tasks to be performed on the same stimuli.

Procedure. The procedure was identical to that used in all prior experiments except that participants performed a top/bottom discrimination task on the odd-colored target for common trials and a left/right discrimination task on the odd-colored target for rare trials. ‘Left’ and ‘top’ responses were mapped onto the ‘z’ key and ‘right’ and ‘bottom’ responses were mapped onto the ‘/’ key. An illustration of the procedure can be found in Figure 4a.

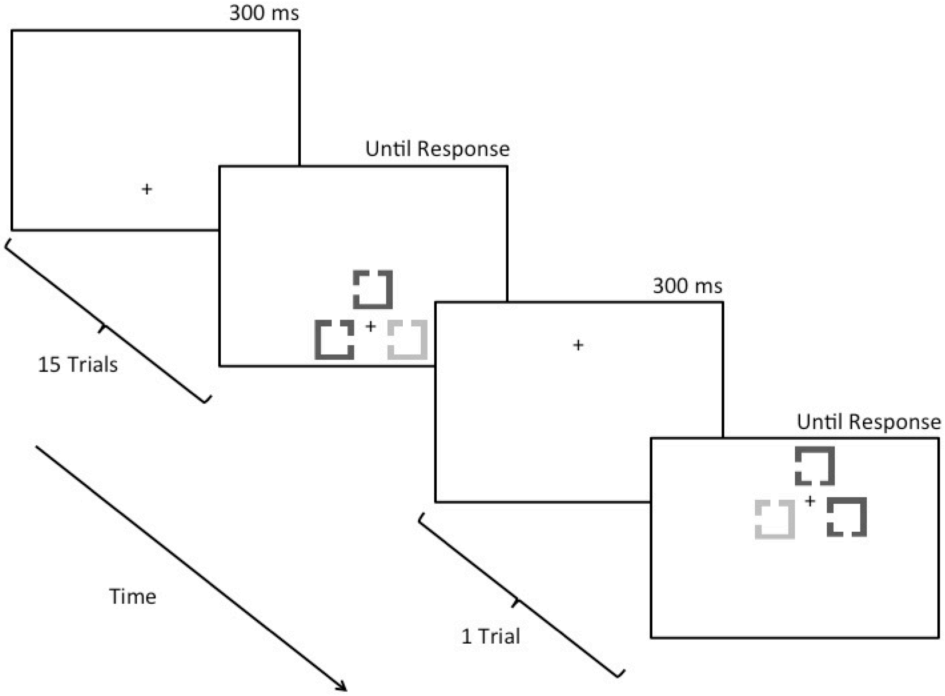

Figure 4a. A depiction of the procedure used in Experiment 4, in which participants locate and respond to a gap in the odd-colored square in each display. Stimulus displays remained on the screen until a response was executed and then after a 500 ms blank interval, the fixation cross for the next search array appeared. Participants performed 15 trials with one task assignment (top/bottom decision) followed by one trial with the opposite task assignment (left/right decision).

Results

The outlier elimination procedure removed 2.7% of the observations. Mean response times and corresponding error rates are shown in Table 4. Mean response times for target repetitions/switches as a function of influencing trial are shown in Figure 4b.

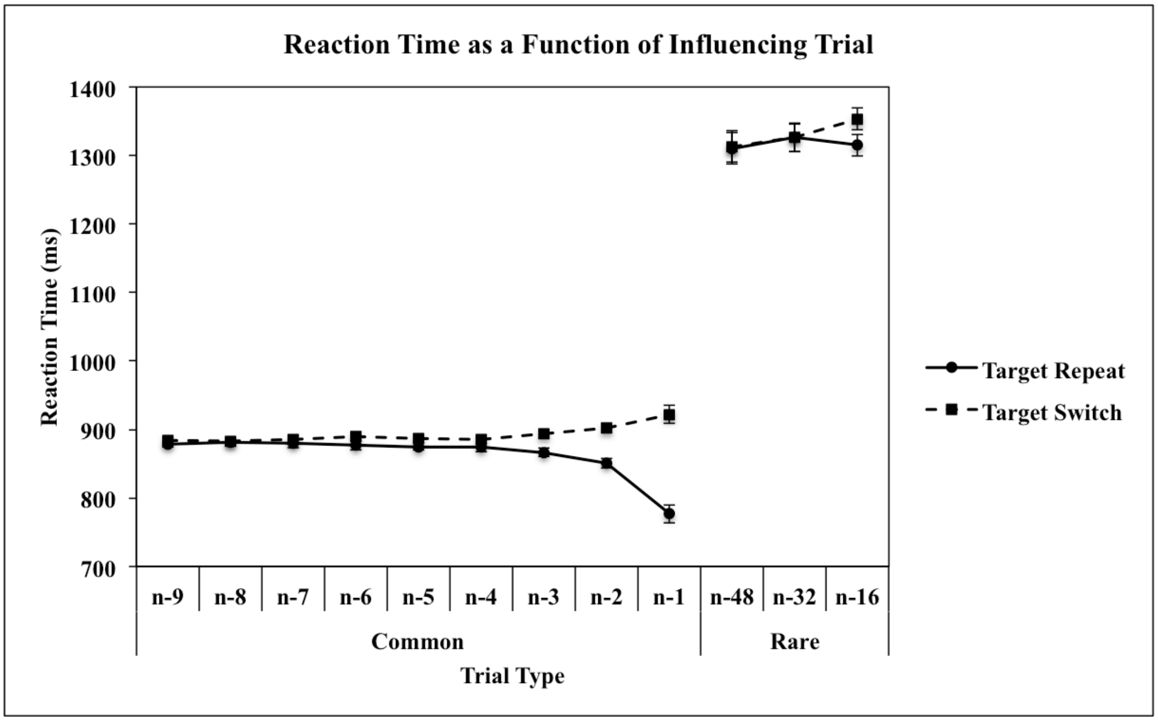

Figure 4b. Reaction time is shown for target repetitions and alternations as a function of the prior influencing trial for both common and rare trial types. Error bars represent standard errors of the mean of the priming effects (target switch – target repeat).

Response times. There was a significant effect of trial type, t (27) = 13.07 , $p < .0001$, $d = 2.43$, with reaction times being faster for common trials (849 ms) than for rare trials (1334 ms).

In order to assess the magnitude of the PoP effect on the current trial as a function of the previous influencing trials, planned comparisons were conducted that compared target repetitions and alternations. For the common trials, these analyses indicated significant PoP effects on the current trial as a function of the following influencing trials: *n*-1 (145 ms), *t (*27) = 11.27, *p* < .0001, *d* = 1.09, *n*-2 (52 ms), *t (*27) = 7.69, *p* < .0001, *d* = .36, *n*-3 (27 ms), *t (*27) = 4.66, *p* < .0001, *d* = .18, *n*-5 (12 ms), *t (*27) = 2.32, *p* = .028, *d* = .08. No significant PoP effect was observed on trial n as a function of trial *n*-4 (11 ms), *n*-6 (13 ms), *n*-7 (5 ms), *n*-8 (1 ms) and *n*-9 (6 ms).

Importantly, for the rare trials these analyses revealed a significant PoP effect at *n*-16 (38 ms), *t (*27) = 2.43, *p* = .022, *d* = .14, but not at *n*-32 (0 ms) or *n*-48 (3 ms).

Table 4. Mean error percentages (M) and standard deviations (SD) in Experiment 4 for common and rare trial types as a function of target (repeat/switch) on trial *n* as a function of the previous trial (*n*-1 for common trials, *n*-16 for rare trials).

	Trial Type			
	Common		Rare	
	μ	(SD)	μ	(SD)
Target Repeat	5.8	(2.6)	7.7	(6.3)
Target Switch	7.2	(3.4)	8.5	(7.3)

Error rates. The analysis of error rates revealed no significant difference in error rates between common (6.5 %) and rare trials (8.1 %), although numerically, more errors were committed on rare than common trials (where rare trials constitute task-switch trials in the present experiment). In the analysis of the common trials, more errors were committed on target switches (7.2 %) than target repetitions (5.8 %), *t (*27) = 4.32, *d* = .49, *p* = .0002, from trial *n*-1 to trial n. In the analysis of the rare trials, there was no significant difference in error rates for target repetitions (7.7 %) and switches (8.4 %) from trial n-16 to trial n.

Discussion

The purpose of Experiment 4 was to examine whether a task-relevant, but target-irrelevant manipulation of contextual distinctiveness between common and rare trials would produce the long-lasting PoP effects observed in the previous experiments reported here. The rationale was as follows: if the long-lasting effects observed thus far are the result of episodic retrieval processes, then it ought be to possible for something other than the target-defining dimension (color) to serve as a contextual cue for retrieval of the most recent rare trial episode. Recall that a modified activation/suppression account of PoP could be invoked to explain PoP from one rare trial to the next when those trials are composed of different target/distracter colors than the intervening common trials. To that end, participants performed different tasks on common and rare trials. The results were clear, in that *n*-16 PoP was observed from one rare trial to the next, despite the fact that the stimulus arrays for the two trial types were identical. This result suggests that top-down information regarding task-set was sufficient to differentiate rare trials from common trials and reduce retrieval interference from intervening common trials. Note that the PoP effect for common trials lasted only about 5 trials, whereas significant PoP emerged for rare trials even though the most recent rare trial occurred 16 trials back.

It is worth noting that we did not counter-balance the task assignments to rare and common trial types between participants in this experiment. This property of our design deserves some comment. Recall that both tasks (left/right and top/bottom) were assigned to the same response keys. This procedure made one task more difficult than the other, as for one task, left/right targets were responded to with response keys are on the left and right (the easy task), while for the other task, top/bottom targets were responded to with response keys again on the left and right (the hard task). Evidence from the implicit sequence learning literature suggests that when participants switch from a well-learned task to one that requires increased cognitive control, reliance on the learned statistical structure inherent in prior trials is often not expressed in performance (Jimenez, Vaquero & Lupianez, 2006). Wary of this type of effect, we opted to have participants switch to a rare task with a relatively easy stimulus-response mapping, rather than vice-versa. However, we have since explored this issue systematically in an experiment that did counterbalance the assignment of task (easy versus hard) to the rare and common trial types. The key result from this experiment was that a statistically reliable 69 ms long-term PoP effect was observed again with the method used in the present experiment (the easy rare task), whereas the long-term PoP effect was not observed when participants switched from an easy common task to a hard rare task. This result constitutes a replication of the key result reported here in Experiment 4, while also confirming that the expression of prior learning in performance can be modulated by the difficulty of the task to which one switches (see Jimenez, et al., 2006).

In summary, a long-term PoP effect was measured in this experiment, suggesting that task served as an effective contextual cue. By this view, a rare trial target cued the retrieval of the most recent rare trial episode, leading to faster responses to target repeats than target switches defined relative to the rare trial episode that occurred 16 trials back.

Importantly, this long-term PoP effect occurred despite the fact that intervening common and rare trial types were perceptually identical.

General Discussion

The primary purpose of the experiments reported here was to demonstrate that priming of pop-out could be observed from one search trial to the next across a large number of intervening items, and to assess whether this effect depended on the contextual distinctiveness of 'rare' search trials with respect to intervening 'common' trials. Previously, PoP has been shown to 'persist' for around 5-8 trials at the most (Maljkovic & Nakayama, 1994). This has led some researchers to posit that passive decay of abstract feature weights diminishes the influence of a prior trial on current performance as time passes, and those weights return to baseline (Goolsby & Suzuki, 2001; Lamy et al., 2008; Lee et al., 2009). An alternative explanation is that as the number of intervening items between a prior influencing trial and the current trial increase, memory retrieval processes suffer due to the build-up of interference. Until now, interpreting the short-lived nature of the PoP effect with respect to either of these theoretical frameworks has been difficult because the passage of time between an influencing trial and a current trial has always been confounded with intervening search experiences. Therefore, the hypothesis of the present series of experiments was as follows: if PoP is driven primarily by memory retrieval processes, then a reduction of retrieval interference from the trials that intervene between the influencing and current trial should allow PoP to be observed across a large number of intervening experiences. A prior study of ours showed that this effect could indeed occur, when trial *n* and *n*-16 are composed of different target/distracter colors than the 15 intervening search trials (Thomson & Milliken, under review). The primary goal of the experiments reported here therefore, was to examine the extent to which properties other than that which defines pop-out could serve as the contextual cue for long-lasting PoP.

Across all four experiments we manipulated every 16th search trial such that these 'rare' trials consisted of perceptual (Experiments 1-3) or task-related (Experiment 4) attributes that distinguished them from the intervening 'common' trials. It was shown that when rare trials were composed of unique target/distracter colors compared to common trials, that long-lasting PoP was observed (Experiments 2 and 3). This result constitutes a long-lasting PoP effect since such effects have previously been shown to last only 8 trials at the most, whereas here we show that PoP can last at least 16 trials (see also Thomson & Milliken, under review). Although target/distracter color produced long-lasting PoP from one rare trial to the next, search array location as well as target/distracter configuration failed to add measurably to this effect. From the results of Experiments 2-3 therefore, we can conclude that salient, target-defining stimulus dimensions such as color produce strong representations in memory that can exert their influence on performance even after a large number of intervening experiences. The same cannot be said however, for less salient, task-irrelevant dimensions such as stimulus location or target/distracter configuration. In this light, the results of Experiment 4 were particularly important. The PoP for rare trials in this experiment showed that a distinctiveness manipulation for common and rare trial types need not be tied to the target-defining dimension (color), but instead can be related to top-down goal-related information, such as what task is to be performed on the two trial types. This result constitutes the first demonstration of long-lasting PoP (*n*-16), with perceptually identical search arrays.

There are therefore three primary findings from the present work that have implications for theoretical accounts of memory in PoP. First, the reduction of the PoP effect as a function of the influencing trial depends heavily on the similarity of intervening search trials to the current and influencing trial. Put differently, the reduction of PoP as a function of intervening items is not a passive process, but an active one. Secondly, PoP is not as short-lived as has been thought, since we have shown PoP effects here (and in our prior work) for rare trials that survive at least twice as long as that for common trials. Finally, producing long-lasting priming effects in singleton search does not seem to require that current and influencing trials differ from the intervening trials along a target-defining dimension (color).

Activation/Suppression Accounts of PoP

The primary purpose of these experiments was to distinguish between two theoretical explanations of the short-lived nature of the PoP effect. One such theory, referred to generally as an activation/suppression account, posits that PoP is driven by activation and suppression of abstract feature gains that represent the possible target features. As time passes, these gains return to baseline and the influence of a prior experience on current performance diminishes. Importantly, these feature gains are set independently of one another (Maljkovic & Nakayama, 1994; Lee et al., 2009). In order to account for the present results within this framework, significant theoretical revisions are required. First and foremost, the 'decay' of target feature gains across time is clearly not an entirely passive process. This is evidenced by the fact that PoP effects diminished rapidly for common trials (within 4-8 trials) whereas the decay of feature gains associated with the rare trials decayed at a much slower rate and persisted for at least 16 trials. One could therefore argue that feature gains set on a given rare trial decay slowly in the absence of the need to re-modulate those weights while performing common trials, and that this slow decay of activation for rare trials explains why PoP can be measured across 15 intervening common trials.

Although this interpretation may well explain the findings of Experiments 2 and 3, the results of Experiment 4 preclude an explanation based solely on the transient persistence of a memory trace for feature information. Recall that the stimuli for both the common and rare trial types were perceptually identical (save for their spatial location, which produces no measureable priming effects as per Experiment 1). Thus, variants of the activation/suppression account of PoP would have to be revised significantly to somehow explain the decay of a feature gain for say 'red' within 5-8 trials, that suddenly re-emerges several trials later, in addition to the adoption of an active decay process.

Episodic Retrieval Accounts of PoP

While it is not entirely clear how the present results could be explained within a modified activation/suppression framework, they could be explained within an episodic retrieval framework quite easily. According to this view, the PoP effect is driven by retrieval of prior episodes from memory that are cued by the current stimulus. To the extent that a particular prior experience matches strongly with current perception and matches poorly with other prior experiences, the probability of retrieval of that particular prior experience will be high, and priming will be observed. These episodic memory representations are integrated representations that are stored in memory and later retrieved. According to this theory, the contextual distinctiveness of the rare trials with respect to the common trials functions to reduce retrieval interference from intervening items, such that if the current trial is a rare trial, it will uniquely cue the retrieval of the most recent rare trial episode. This theory predicts that PoP effects could be measured across a large number of intervening experiences provided that appropriate retrieval cues are present (Morris, et al., 1977; Logan, 1988, 1990). In other words, the distinct attributes that were associated with the rare trials (i.e. unique target/distracter colors or unique task-set information) function as contextual cues for the retrieval of other episodes that were laid down in memory in that same context.

One potentially important issue with respect to interpreting the results of the present experiments within an episodic retrieval framework is that under this theory, almost anything can serve as a contextual cue for the retrieval of prior episodes, whereas target/distracter color and task were the only things that produced long-lasting PoP here. Future work will be needed to discern what, if anything, is required in order for other contextual properties of search displays to guide performance, such as stimulus location and stimulus configuration (that are irrelevant to both target localization and response selection). Nonetheless, we believe that interpreting the present results within an episodic retrieval framework provides the most parsimonious account of the memory representations underlying long-lasting PoP at present.

Relation to Other Work

Recently, other researchers have implicated episodic retrieval operations in singleton search tasks. For example, Hillstrom (2000) demonstrated interactions in performance as a function of the repetition/alternation of target-defining and response-defining features in a pop-out search task. As a result of the fact that these low-level target features seemed to be bound or integrated in memory, Hillstrom interpreted such results within an episodic retrieval framework, in which a bound representation is stored in visual working memory (VWM) on one trial, and is subsequently recruited from VWM on the next trial. While our account of PoP is somewhat similar to that of Hillstrom (2000; see also Huang, et al., 2004), it seems unlikely that the effect of one rare trial on the next in the present study is driven by memory recruitment from VWM. Recall that there were 15 intervening common trials between each pair of rare trials and so in order for a rare trial episode to be recruited from VWM on the next rare trial, VWM would have to contain at least 16 distinct search experiences, which is well beyond most estimates of WM capacity (see Luck & Vogel, 1997). We therefore argue that if memory episodes drive performance in the present study, that these episodes exist in a more durable form. Thus, rather than assuming that such episodes are retrieved from VWM, we take the somewhat more agnostic stance that they are retrieved from memory, over the short-term in some cases, but in other suitable cases over the long-term.

While the present series of experiments are the first to demonstrate long-lasting PoP effects, they are not the first demonstrations context effects on singleton search performance. Kristjansson, Sigurjonsdottir and Driver (2010) demonstrated that when one of two potential target colors in a color pop-out search task was associated with a high reward relative to the other target color, response times were expedited for high-reward targets relative to low-reward targets. In addition, they demonstrated that PoP was greater for high-reward relative to low-reward targets. Although they interpret such findings as representing increased feature priming for high-reward targets, this result nonetheless demonstrates that low-level aspects of a search array can function as a context with which to cue target color-specific processes. Similarly, Geyer, Zehetleitner and Muller (2010) demonstrated contextual cueing effects (see Chun & Jiang, 1998) with singleton search displays, suggesting that as experience accrues in singleton search tasks, target and distracter configurations are stored in memory, just as is the case for conjunction search. Therefore, the results reported here converge with those of Geyer et al. in suggesting that the recruitment of episodic representations of similar prior experiences can support performance in singleton search.

The results of Geyer et al. (2010) are particularly interesting when contrasted with the null effect of stimulus configuration on long-term PoP observed in the present study. In particular, it is noteworthy that to observe cueing effects with singleton search displays, Geyer et al. had to provide participants in their study with a 700 ms preview of distracter locations (i.e., the contextual cue) before onset of the search display. They argued that priming effects in singleton search are the result of a combination of bottom-up priming and top-down memory retrieval, where bottom-up processing unfolds much faster than top-down control. As a result, top-down processes must be given a 'head start' in order to affect, or 'boost', bottom-up processing. With this idea in mind, it may be that in the present study, contextual aspects of a search array, such as location (Experiment 1), and configuration (Experiment 3) are being encoded in memory on each trial (albeit not to the extent of task-relevant information), but do not influence PoP effects for rare trials because the influence of contextual re-instatement on these dimensions unfolds too slowly to be measured. Future experiments that provide participants with location and configuration previews offer a potential path to study this issue in more detail.

The adoption of episodic retrieval operations as the most suitable explanation of the present result does not preclude the role of bottom-up priming in singleton search, as has been argued recently (see Kristjansson & Campana, 2010; Asgeirsson & Kristjansson, 2010; Geyer, et al., 2010). These researchers have argued that when search is particularly efficient (i.e. the pop-out target has a very high contrast with respect to the distracters), bottom-up feature priming predominates search performance from one trial to the next. In contrast, when search is more difficult, priming effects can be measured that are in accord with episodic retrieval operations. Thus, activation/suppression and episodic retrieval explanations of the PoP effect may both be correct, with the relative contributions of these two influences depending on the particular task demands and constraints placed on participants (Lamy, Yahsar & Ruderman, 2010; Asgeirsson & Kristjansson, 2011; Lamy, Zivony & Yashar, in press; Yashar & Lamy, in press). Nonetheless, it is worth noting that if one were to follow the path of looking for a single mechanism underlying priming effects in singleton search, this mechanism would have to incorporate some role for the types of contextual principles that have long been known to affect remembering over the long term.

Conclusions

We have shown that PoP effects can be measured across at least 15 intervening search trials, which is twice as many as has been shown previously. Presenting rare trials in unique target/distracter colors allowed us to measure the influence of those trials on subsequent rare trials (16 trials later) despite the fact that the influence of a given common trial could only be observed 4-8 trials later. In addition, this long-lasting PoP effect was observed even when common and rare trials were distinguished from one another along a target-irrelevant attribute (i.e., task). This novel effect demonstrates that PoP is not as short-lived as has been thought, and that the nature of intervening search experiences between the current and influencing trial has a large impact on whether or not PoP can be observed. We argue that even when simple, efficient search is performed, a durable representation is laid down in memory that includes contextual information, and that context-cued retrieval of these prior experiences can influence performance on subsequent search trials provided that interference from intervening experiences is at a minimum.

CHAPTER 6: General Discussion

Priming effects in human performance tasks are often explained by 'transient', short-term mechanisms that make no reference to memory retrieval processes. As discussed in the introduction to this thesis, there is a long history in cognition of considering memory retrieval and priming as distinct cognitive processes that rely on separate neural substrates, and that impact behavior in very different ways (Tulving & Schacter, 1990; Schacter, 1992; Tulving, 1995; Wiggs & Martin, 1998). One of the broad aims of this thesis was to examine whether the retrieval of particular memory episodes and priming need necessarily be thought of as distinct.

Indeed, the idea that at least some priming effects can be explained by reference to the automatic retrieval of memory episodes has gained significant empirical support. These observations have been made in tasks that measure conflict adaptation (Spape & Hommel, 2008), negative priming (Grison, Tipper & Hewitt, 2005), inhibition of return (Wilson, Castel & Pratt, 2006), task-switching costs (Mayr & Bryck, 2005) and contextual cueing (Chun & Jiang, 1998), to name just a few. Despite this evidence in support of a role for episodic retrieval in performance tasks, a convincing episodic explanation for priming effects in efficient visual search has thus far eluded researchers. The primary goal of the experiments reported within this thesis, therefore, was to provide a rigorous empirical investigation of the predictions of an episodic retrieval account of priming in singleton (efficient) search.

Transient activation/suppression accounts of PoP assert that the memory underlying the effect contains only low-level perceptual information (Lee, Mozer & Vecera, 2009), whereas episodic retrieval theories accept that both low-level features and top-down contextual information can be integrated in the underlying memory representation (Hommel, 2004; Mayr & Bryck, 2005). Chapter 2 showed that when the response selection task switched from one trial to the other, priming of pop-out for color and shape-defined targets was significantly diminished (Experiments 1, 2 and 4) even when the perceptual properties of the search displays were unchanged (Experiment 4). This result suggests that the memory underlying PoP does not contain strictly low-level information, and constitutes a first piece of evidence for the role of episodes in singleton search. Activation/suppression accounts argue that time alone is sufficient to eliminate the PoP effect, as feature gain potentiations will eventually return to baseline (Maljkovic & Nakayama, 1994; Goolsby & Suzuki, 2001; Lee et al., 2009), whereas episodic retrieval theories predict that even after a significant amount of time, there remains some probability of retrieving the *n*-1 episode and so PoP may diminish over time, but will not be eliminated across time alone (see Deschepper & Treisman, 1996 for an application of this principle to the negative priming effect). Chapter 3 demonstrated that PoP effects do indeed diminish over time, but that the influence of the previous trial on the current trial still remained after 16 seconds. Finally, activation/suppression accounts of PoP argue that the short-term nature of the effect is due strictly to passive decay (Maljkovic & Nakayama, 1994, Lamy, Antebi, Aviani & Carmel, 2008), whereas episodic retrieval theories posit that interference from intervening items plays a significant role in the probability of retrieval of a given prior episode (see Wilson, Castel & Pratt, 2006 for an application of this principle to the inhibition of return effect). Chapter 4 demonstrated that when ‘rare’ search displays were made perceptually distinct with respect to ‘common’ trials, long-lasting PoP was observed, an effect that survived twice as many intervening experiences as had been shown previously in the literature. Furthermore, Chapter 5 demonstrated that this long-lasting priming could be observed even when common and rare search displays were composed of the same targets and distracters.

Taken together, the fact that PoP is affected by non-perceptual information, still persists after 16 seconds (and may last much longer than that), and benefits from a reduction in retrieval interference, it seems likely that when efficient search is performed, a robust episodic representation is created in memory. I will next discuss whether this conclusion precludes the role of activation/suppression mechanisms in pop-out search before connecting the behavioral work reported here with recent physiological observations, and then finally discussing the implications of the present work with regards to the broader memory and attention literature.

Dual-Stage (Hybrid) Accounts of Priming of Pop-Out

Two leading theoretical explanations of the memory mechanism underlying the priming of pop-out effect in visual search have been contrasted with one another as a means to generate novel empirical questions throughout the experiments presented within this thesis. Activation/suppression and episodic retrieval accounts of PoP differ markedly in terms of the type of information represented in memory that causes PoP, in the time-course across which such memory representations can produce PoP, and in the mechanism by which ‘forgetting’ of the critical memory representations occurs. Although it has been argued here that the evidence obtained within the empirical chapters of this thesis is best accounted for by an episodic view of priming in efficient search, some researchers have argued that the two leading accounts of PoP need not be mutually exclusive, and that in fact, more than one process may contribute to performance in pop-out search from one experience to the next. These dual-process, or ‘hybrid’ accounts of PoP will be described briefly before assessing whether or not the data presented here fit within such a conceptualization.

Activation/suppression accounts of PoP have been referred to by some researchers simply as feature-based, or attentional accounts of priming in singleton search, to get at the idea that the memory trace underlying PoP affects processing at a relatively early stage in search; mainly the allocation of attentional resources to previously attended features (Lamy, et al., 2010). Similarly, episodic accounts of PoP have been referred to as late-stage, or response selection accounts, to get at the idea that memory representations from the preceding trial cannot be compared with current perception until after attentional resources have been allocated to salient features in the display; mainly, the target. It has recently been argued that such feature-based and late stage memory influences may both contribute to priming effects in singleton search. A key piece of evidence for this view is that priming effects for task-relevant and irrelevant features sometimes occur simultaneously, but in an independent and additive manner, as predicted by activation/suppression theories (Kristjansson, 2006; Kristjansson, Inguardsdottir & Teitsdottir, 2008). Other times, priming effects for task-relevant and irrelevant features occur in an ‘all-or-none’ manner, meaning that both task relevant and irrelevant features must be repeated in order for facilitative priming to be observed, as predicted by episodic retrieval theories (see Huang, Holcombe & Pashler, 2004). For example, Kristjansson, et al., (2008) had participants locate a target from amongst homogeneous distracters, where each item in the display consisted of two colors, and the odd color combination defined the target. In their ‘split’ condition, search items had one color on the left and another on the right, whereas in their 'object' condition, search items were composed of a diamond of one color, with a smaller diamond embedded within them of a different color. Importantly, they found simultaneous, but independent (additive) priming for the colors that defined the target in the split condition, but that both colors had to be repeated in order for priming to be observed for the object condition. This result suggests that whether or not PoP is driven primarily by feature-based or late-stage memory influences depends on whether or not the features lend themselves to object-based perception. It is argued that this account fits well with the observation that independent priming is observed for color and motion (Kristjansson, 2009) as well as for color and spatial frequency (Kristjansson, 2006), but that non-independent priming is observed for color and orientation (Huang et al., 2004). Priming in singleton search may therefore be driven by both attentional and late-stage memory influences, where the relative influence of one over the other depends heavily on the particular stimuli and task demands used (see Kristjansson & Campana, 2010 for a recent review of this idea).

Lamy, et al. (2010) have provided additional evidence in support of dual-process accounts of priming by demonstrating that independent priming of multiple features (target-defining and response-defining) is observed when displays are presented briefly to participants (100 ms) but that repetition or alternation of one or both of these features produces interactions in performance when displays are visible for a longer period of time (~ 400 ms). This has been interpreted as evidence for both an early perceptual, and later response based locus of PoP. Additionally, the emergence of late-stage retrieval processes is believed to be highly dependent on the difficulty of search. For example, Lamy, Zivony and Yashar (in press) observed interactions between repetition/alternation of target-defining and response-defining features only when the relative salience of targets with respect to distracters was low. Similarly, Yashar and Lamy (in press) observed interactions between repetition/alternation of response feature and motor response only when search was made more difficult. Furthermore, Asgeirsson and Kristjansson (2011) conducted a series of experiments aimed at determining the conditions under which the interaction between task-relevant and irrelevant feature repetitions would occur in the procedure used by Huang et al. (2004) and found that such interactions only occurred for 'difficult' search.

Taken together, recent evidence seems to suggest that while 'bound' or integrated memory representations can indeed affect performance in singleton search tasks from one trial to the next, measuring such influences seems dependent on the nature of the particular stimuli from which search arrays are composed. Mainly, episodic-like representations can guide search when (1) the features from which search items are composed can easily be perceived as whole objects, (2) the relative salience of targets with respect to distracters is low and therefore search is made more difficult (which presumably increases the utility of reliance on memory retrieval processes), and (3) search arrays are presented long enough for processing to proceed to the post-attentional stage. Although a dual-process theory of inter-trial priming in singleton search is more in line with the data presented within this thesis than a strict activation/suppression account, some properties of the data presented here remain a challenge for dual process theory, at least as currently stated (see Lamy et al., 2010; Lamy et al., in press; Yashar & Lamy, in press).

The empirical data presented in this thesis demonstrated that repetition/alternation of perceptual (target feature) and non-perceptual (selection task) information from one trial to the next produced interactions in performance in a color pop-out task (Chapter 2). This result was taken as strong evidence for bound, episodic-like representations underlying PoP. While the post-attentional component of dual-process theories of PoP allows for the recruitment of integrated representations during search, this memory is feature (and to a lesser extent, motor) based. In order to account for the effect of switching task that occurs without changes in perceptual attributes of the search displays, dual-process accounts would have to be expanded to include non-perceptual, task-relevant information. In addition, an interesting finding in Experiment 4 of Chapter 2 was that the modulation of PoP that occurred with a task switch was only observed when target-distracter discriminability was high, rather than low. This result conflicts with the idea that bound, or integrated representations only affect performance when search is made more difficult. It is unclear whether the task difficulty effect observed in Chapter 2 is stable, and further work is required to understand fully the task requirements and conditions that produce the observed interactions. Nonetheless, the data as they stand, require at least some revision to the dual-process account of PoP.

Chapters 4 and 5 demonstrated that PoP effects could be observed across a large number of intervening items, provided that target-defining or task-defining contextual properties varied between ‘rare’ trials and the intervening ‘common’ trials. The post-attentional component of dual stage theories argues that episodic influences can impact search performance, but that these episodic representations are likely recruited from visual working memory (see Hillstrom, 2000). It is unlikely that the rare trial priming effects observed in Chapter 4 as well as Experiments 2, 3 and 4 of Chapter 5, are due to retrieval from working memory, since those memories would have been laid down 16 trials back. As a result, the long-term nature of the priming effects observed in Chapter 4 preclude a simple dual-process explanation of the data presented here. While it is entirely possible that the retrieval of bound episodic-like memory representations are recruited from visual working memory when priming is measured on the current trial as a function of the immediately preceding trial, a more stable, long-term memory mechanism would need to be invoked to explain the *n*-16 priming effects observed within this thesis.

Taken together, dual-process accounts of priming in singleton search represent a shift in theoretical perspective relative to theoretical proposals in which activation/suppression of feature gains and episodic retrieval are mutually exclusive. The key contention in dual-process accounts is that episodic representations are retrieved under difficult search conditions. Although this contention makes sense of seemingly contradictory data in which repetition of target-relevant and irrelevant features sometimes produces interactions in performance and sometimes produces additive effects, the target-distracter discriminability effect observed in Chapter 2 does not fit within this idea. In addition, dual-process theories of PoP describe episodic influences as recruited from a short-term memory store (visual working memory), which might well explain priming effects observed from trial *n*-1 to trial *n*, but cannot explain the long-term (*n*-16) priming effects observed in Chapter 4 and Chapter 5 within this thesis. The data reported here cannot rule out the influence of transient short-term memory traces that affect early perceptual stages of efficient search. However, it has been shown that priming of pop-out exhibits many properties that have long been argued to reflect the operation of episodic memory representations that are recruited implicitly and automatically. Although a modified dual-process account of PoP may well explain the findings reported here, any argument that attributes PoP solely to the activation/suppression of abstract feature gains is insufficient.

Physiological Evidence for the Mechanisms Underlying PoP

This thesis has focused on behavioral methods in which reaction time and accuracy differences between repeated and alternated stimuli define the PoP effect. Some recent research has turned to physiological measures to further understand the PoP effect. The following sections are selective reviews of some recent empirical work on the PoP effect that have exploited Trans-cranial Magnetic Stimulation (TMS), functional Magnetic Resonance Imaging (fMRI), and Electroencephalography (EEG), to better understand the physiology as well as the neural substrates that underlie inter-trial priming in singleton search.

Trans-cranial Magnetic Stimulation

Trans-cranial magnetic stimulation (TMS) is a tool used by researchers to disrupt small cortical areas in order to gain a better understanding of the function of those brain areas, and it has been used recently by researchers interested in the brain areas responsible for mediating the PoP effect in visual search. For the most part, TMS findings have been offered as convergent support for early attentional (feature priming) accounts of PoP. The evidence for this conclusion will be described briefly.

One of the first applications of TMS to the study of visual search examined the basic premise that singleton search occurs in parallel across a search scene, while conjunction search involves a more difficult, serial search. Ashbridge, Walsh and Cowey

(1997) applied TMS to right parietal visual areas that are believed to be involved in spatial processing and examined the behavioral consequences that such disruption had on both conjunction and singleton search. Importantly, they found that when TMS was applied early in a search trial, the efficiency of conjunction search performance decreased markedly, whereas there were no observable effects on singleton search. This was taken as evidence that simple detection of an odd-ball target does not require the use of brain areas responsible for spatial allocation of attention and that such efficient search does indeed proceed in a parallel manner. It has been shown more recently however, that performing a compound[1] singleton search task (which has been known to produce location priming effects as per Maljkovic & Nakayama, 1996; see also Geyer, Muller & Krummenacher, 2007) does require spatial attention, and that the resultant spatial priming effects may be mediated by the frontal eye fields (FEFs). For example O'Shea, Cowey, Muggleton and Walsh (2007) demonstrated that TMS to the FEFs had a significant impact on spatial priming, but not feature priming, when TMS was applied during the presentation of a color pop-out search array. Because applying TMS during the inter-trial interval had no effect on spatial priming, it was argued that the FEFs play a crucial role in integrating a spatial memory trace with current attentional selection, but do not mediate the actual storage of such a memory trace. The authors argue that these findings are in line with 'repetition suppression' of BOLD signals observed in fMRI studies in which the re-presentation of a percept results in less cortical activation. Put differently, the role of the FEF's as revealed through TMS seems more in line with a transient activation/suppression framework of PoP than an episodic retrieval framework.

While it has been shown that the FEF's, but not right parietal visual areas of the cortex, play a role in spatial priming in pop-out search, disruption of the right angular gyrus (rANG) has been shown to negatively affect feature priming. Taylor, Muggleton, Kalla, Walsh and Eimer (in press) showed that rANG disruption during the inter-trial interval of Maljkovic and Nakayama's (1994) color pop-out task affected performance for target color alternations but not repetitions. They argued that such a result was more in line with an early attentional account of PoP than with a response-based (or memory retrieval) account of PoP since only the switch trials were affected (which are the only trials on which the attentional system needs to be updated).

Observations from TMS therefore, seem to suggest separate neural substrates for location and feature priming (the frontal eye fields and the right angular gyrus respectively). Moreover, disrupting these areas both between and during search trials seems to affect performance in ways that have been interpreted as evidence for an attentional locus of PoP. Although this interpretation is reasonable, it may also be the case that such cortical areas predominate the mediation of an early attentional component of PoP, whereas other areas may dominate the mediation of later memory retrieval processes (as in a dual-process account, described in the preceding section). In addition, in studies in which TMS affects performance only when applied during search and not during the inter-trial interval, it may be that the application of TMS disrupts the initial laying down of a memory trace in the first place, despite the fact that such effects are interpreted as affecting attentional selection and not memory retrieval (see O'Shea, Muggleton, Cowey & Walsh, 2007). In summary, there remains much work to be done in order to understand specifically the cortical areas responsible for PoP as revealed through TMS, and while the evidence to-date is largely interpreted as refuting a memory retrieval interpretation of PoP, it does not unequivocally do so.

Functional Magnetic Resonance Imaging

Functional Magnetic Resonance Imaging (fMRI) is a tool used by researchers to examine activity of the brain in response to various tasks and stimuli. fMRI measures blood-oxygen level dependent (BOLD) activity which is used to posit which areas of the brain are more or less active during an experimental context. Although there has been relatively little research on the PoP effect using fMRI, one recent study provides some important insights into the neural substrates of feature priming in singleton search.

Kristjansson, Vuilleumier, Schwartz, Macalusso and Driver (2007) were the first to examine the neural correlates of location and color priming in the paradigm used by Maljkovic and Nakayama (1994). In particular they were interested in whether brain areas would show BOLD repetition suppression[2] in response to repeated target color, location, or both. The main findings were that repetition of location alone resulted in repetition suppression in the inferior parietal and frontal areas, whereas repetition of color alone resulted in repetition suppression in the inferior temporal area. Interestingly, repetition of both color and location from one trial to the next led to suppressed BOLD activity in the intra-parietal sulcus and frontal eye fields – areas that have been implicated in the control of attention. In general, the brain areas associated with repetition suppression demonstrate that particular feature repetitions result in suppression of distinct brain areas and that repetition of multiple features in a pop-out search task results in suppression in areas associated with the control of attention. Although the authors do not explicitly interpret these results as supporting an activation/suppression over a memory retrieval account of PoP, they do speculate that the activation patterns in the attention network may reflect an 'attracter' state in which the attention network is biased towards recently viewed stimuli. This seems analogous to the attentional (or early perceptual) view of PoP, in which the memory mechanism driving PoP primarily affects the allocation of attention to the target early in processing, before episodic-like memory retrieval processes can occur. Indeed, the color and location priming effects observed in this study were independent and additive, suggesting that perhaps the particular task demands (high distracter salience) facilitated early attentional priming, but not later-stage memory retrieval operations, as per a dual-process account of PoP.

Although there is relatively little research on the neural substrates of the PoP effect as revealed through fMRI, the existing data seem to reveal that many cortical areas respond differentially to the repetition of many features of a search display from one trial to the next in a pop-out search task. It makes sense that early visual areas of the brain would show differential patterns of activation in response to repeated visual features relative to switches, and that joint repetition of visual features would show differential patterns of activation in higher-level cortical areas responsible for the deployment of attention. Although these findings could potentially be interpreted within an activation/suppression account of PoP, they also easily fit within a dual-stage account of PoP, in which processing did not proceed to the memory retrieval stage due to the particular stimuli used. As such, assessing repetition suppression using fMRI may yield substantially different results if applied to search tasks in which memory retrieval processes are argued to occur, such as the task used by Huang et al. (2004), or the tasks used in chapters 2, 4 and 5 of this thesis.

Event-Related Electroencephalographic Potentials

Event –related potentials (ERPs) are voltage changes that occur in particular areas of the cortex that can be measured with fairly precise temporal resolution, using scalp-mounted electrodes. ERPs are described as waveforms that result from averaging electrical activation over a large number of experimental trials, and can be used to infer which areas of the brain are involved in producing certain behavioral phenomena. ERPs have been relied upon to better understand visual search processes in humans, and recently, have been employed as a means to better understand the PoP effect.

The wave-form most often studied in the context of visual search and inter-trial feature priming is the N2PC component. The N2PC is a negative voltage component observed in posterior cortical areas, typically in the hemisphere contralateral to stimulus presentation, and occurs around 200 ms post-stimulus. It is typically observed when a target item in the visual field differs along a salient dimension from other, distracting items (Luck & Hillyard, 1994), and is believed to reflect attentional selection processes (Eimer, 1996). As a result, researchers have posited that if the priming of pop-out effect is primarily driven by early perceptual target selection, then differences in N2PC components should be observed for target feature repetitions and alternations in a color-pop-out search task.

Eimer, Kiss and Cheung (2010) had participants search for an odd-colored item amongst homogeneous distracters in a color pop-out task. Importantly, they examined whether target/distracter color repetitions/alternations would affect the N2PC waveform.[3] They hypothesized that if the PoP effect primarily modulates early perceptual processing (the efficiency of directing focal attention to the target) then PoP should be accompanied by changes in the N2PC waveform. In contrast, if PoP is driven solely by response-based, or late-stage processes (such as episodic retrieval), then no effects of PoP on the N2PC should be observed, since the N2PC is associated with selective attention processes that occur early in search (~200 ms post-stimulus). It was found that target color repetitions resulted in earlier N2PC onset, relative to switches, suggesting that PoP cannot be driven exclusively by late-stage retrieval mechanisms.

Although the earlier onset of the N2PC is argued to be in accord with an early perceptual locus of PoP, Eimer and Kiss (2010) argue that inter-trial priming effects such as PoP, cannot be attributed solely to bottom-up processes, as has been argued by others (see Thueewes, 2010). For example, Eimer, Kiss, Press and Sauter (2009) demonstrated that N2PC onset latencies are determined only by items that match an active task-set, suggesting that top-down knowledge about the features that define the target is critical in modulating the N2PC waveform. Taken together, recent evidence from ERPs suggests that PoP does seem to affect focal attentional selection early in the search process. Although it is argued that this precludes episodic retrieval as the exclusive mechanism underlying PoP, it may well fit within a dual-process account of inter-trial priming effects in singleton search. Future work using ERPs will be necessary to determine whether N2PC onsets are modulated in tasks in which episodic influences on search have been observed. Specifically, it is unclear whether a cortical response that happens so early in processing (200 ms) would be altered when non-independent priming effects are observed for target relevant and irrelevant features, or whether the N2PC would be affected by the re-instatement of context that produces the long-lasting PoP effects observed in chapters 4 and 5 of this thesis.

The previous sections offered selective reviews of three non-behavioral methods of assessing the nature of inter-trial priming in singleton search. The use of rTMS, fMRI and ERPs provides a complementary approach to understanding the physiological as well as behavioral consequences of priming in efficient visual search. The use of physiological measures as a means to understand the priming of pop-out effect is relatively undeveloped in comparison to the wealth of behavioral data that has been collected in recent years. Nonetheless, at least three tentative conclusions can be drawn from the brief reviews described above. (1) observing physiological correlates of behavioral priming in visual search is in many cases exploratory, with little or no explicit theoretical conclusions with regards to the underlying nature of the memory representations that drive such effects, (2) studies examining the locus of the PoP effect seem to converge on the idea that it is primarily the result of changes in early perceptual processing (the allocation of selective attention to the target), (3) many of the reported findings are open to multiple, even conflicting interpretations, and as such, no equivocal evidence against memory retrieval operations exists at present. In summary therefore, it remains an open question as to whether physiological phenomena such as repetition suppression and N2PC onset differences would emerge in search tasks for which episodic influences are observed, such as the effect of switching task observed in chapter 2 here, or the long-lasting priming effects observed in chapters 4 and 5. Future work may shed some light on the neural correlates of episodic-like effects observed in PoP, as more behavioral evidence accrues in favor of such a theoretical interpretation.

Summary and Conclusions

The primary goal of the experiments reported within this thesis was to assess whether the principles of an episodic memory view of priming effects can be extended to include the PoP effect in efficient visual search. The three key properties of an episodic theory of the PoP effect that were tested here are as follows: (1) memory episodes can contain both perceptual and non-perceptual information; (2) memory episodes do not 'decay' rapidly after they are formed; and (3) retrieval interference is a primary mechanism of forgetting. Chapter 2 demonstrated that non-perceptual information, such as the selection task that is to be performed on the target, affects the magnitude of PoP from one trial to the next. Chapter 3 demonstrated that although PoP does indeed diminish across time in the absence of intervening items, the effect appears to follow a power law function with a long-lasting component and minimal decay beyond 16 seconds. Chapter 4 demonstrated that the similarity of intervening search experiences between the current and influencing trial has a high impact on whether or not PoP can be observed, and finally Chapter 5 demonstrated that non-perceptual contextual properties of the search trial can produce long-lasting PoP. Taken together, the evidence presented here suggest strongly that episodic retrieval processes contribute to the PoP effect. Indeed, the idea that PoP is driven exclusively by short-term transient perceptual memory traces can largely be ruled out in light of the present findings. A dual-process account of PoP, in which PoP is driven by changes in early attentional processing and late-stage memory retrieval processes, may well accommodate the results of the experiments reported here (with the caveats that memory retrieval is likely not from a short-term visual store, and that such memories are not strictly perceptual in nature).

Priming and Multiple Memory Systems

The theoretical rationale for this thesis, beyond gaining a better understanding the processes that contribute to memory influences in efficient visual search, was to examine whether priming effects in the context of performance tasks could be explained by reference to general principles of episodic memory. I will very briefly recap the central themes of the argument for separate and distinct systems underlying priming effects and episodic memory, before assessing how the data presented within this thesis contributes to this on going debate.

The historical rationale for a separate systems view is largely based on the differences in phenomenology that accompany priming effects and episodic memory retrieval. Specifically, priming effects reflect implicit effects of prior experiences on behavior and are measured in the context of performance tasks, whereas episodic memories are explicit, or conscious, in nature and are retrieved deliberately and voluntarily (Tulving, 1989; Tulving, 1993; Baddeley, 2004). As a result, these different types of memory have been argued to be stored in, and mediated, by different memory systems (Tulving, 1995). For example, perceptual priming has long been argued to be separate and distinct from declarative forms of memory (Tulving, 1985; Schacter, 1990) and is argued to be mediated by a special perceptual representation system (Schacter, 1992). Regardless of the particular differentiation of memory systems adopted based on phenomenology, one of the central tenets of such a classification scheme is that the memories responsible for skill acquisition are wholly different from those responsible for episodic recollection (Squire, 1992). This idea has been questioned by another camp of researchers, who have argued that episodic-like memory representations are precisely they means by which priming and skill acquisition occur (Logan, 1988, 1990; Kahneman, Treisman & Gibbs, 1992; Hommel, 1998, 2004).

The idea that implicitly created and retrieved memory episodes can guide behavior in the context of performance tasks (as well as nominal remembering tasks) has largely been based on observations that skill acquisition is not a general process, but rather, reflects faster and accurate retrieval of particular prior experiences (Logan, 1988; 1990). These implicitly recruited episodes (or instances) seem to embody many of the same characteristics of standard, explicitly retrieved, memory episodes. For example, they contain action and goal-related information (see Hommel, 1998; 2004), are context-sensitive, and their retrieval is subject to interference effects. Implicitly recruited instances have been argued to drive many priming effects in performance tasks, such as conflict adaptation (Spape & Hommel, 2008), negative priming (Grison, Paul, Kessler & Tipper, 2005), inhibition of return (Wilson, Castel & Pratt, 2006), task-switching costs (Mayr & Bryck, 2005) and contextual cueing (Chun & Jiang, 1998). However, the general idea that priming effects are caused by the retrieval of episodic memory representations is open to criticism to the extent that at least some priming effects seem resistant to an episodic interpretation. To date, the PoP effect may have been one of these effects. The goal of this thesis was to assess whether the PoP effect does indeed require the adoption of specialized memory principles, other than those used to explain priming effects in other performance tasks, or whether the retrieval of episodic memory representations provides a suitable explanation.

The empirical work presented here suggests that PoP effects are driven my memory representations that can include non-perceptual information (chapter 2), can impact performance well beyond 30 seconds (chapter 3), benefit from a reduction in retrieval interference (chapter 4), and are affected by contextual properties of the stimulus display (chapter 5). Taken together, the evidence presented here suggests that when efficient visual search is performed, an episodic representation is laid down in memory.

Footnotes

[1] 'Compound' search simply involves locating a singleton target that is defined on one dimension (e.g., color) and then performing a discrimination judgment on another dimension (e.g., orientation). The vast majority of PoP studies use compound search tasks – see Olivers & Meeter (2006) for a comparison of present/absent vs. compound singleton search tasks.

[2] BOLD repetition suppression is the finding that brain areas that are active in response to a particular percept, show less activation on subsequent exposures. This phenomenon has been shown in many other 'simple' priming tasks, but has never been investigated in visual search. Repetition suppression is believed to reflect a 'sharpening' or 'speeding' of the response of a given neuronal population from one stimulus presentation to another.

[3] When assessing ERPs in response to a stimulus, it is differences in either the onset, duration, or amplitude of a given component that are observed between two conditions – not the presence/absence of that component.

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