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The Role of Action in Priming of Pop Out in Visual Search

by

Blaire J. Weidler

A dissertation presented to
The Graduate School
of Washington University in
partial fulfillment of the
requirements for the degree
of Doctor of Philosophy

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May 2017

ABSTRACT OF THE DISSERTATION

The Role of Action in Priming of Pop Out in Visual Search

by

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Doctor of Philosophy in Psychological & Brain Sciences

Washington University in St. Louis, 2017

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Completion of many daily tasks (e.g., driving, grocery shopping) requires efficient allocation of limited attentional resources. One factor that affects where attention is allocated in a complex scene is previous experience with the environment—participants are faster to examine features which were previously behaviorally important. In the experimental paradigm often used to investigate this phenomenon, called Priming of Pop Out (PoP), participants view a multi-item display, locate a target (defined by a unique feature such as color), and then respond with a keypress. On the next trial, they are often faster to find the target if it shares features with the one on the previous trial. The requirement to respond on each trial of such experiments raises some questions because an independent line of recent research has shown that simply making even an arbitrary action towards an object can influence subsequent visual search. That finding raises the possibility that the results obtained from experiments on PoP may derive in whole or in part from the actions that are produced on each trial—a possibility that could influence conclusions that can be made about the phenomenon. This dissertation explored that possibility by isolating the effect of action from the other cognitive components of the PoP paradigm. Across three experiments, trials in which participants performed the typical PoP task—which requires viewing the stimuli, locating the target, and making a motor response—were

interspersed with atypical trials that removed at least one of those components: in Experiment 1 the atypical task omitted both locating the target and making a response (i.e., participants just viewed the display), in Experiment 2 the response component was omitted and in Experiment 3 the target localization component was omitted. There were two key findings—PoP is robust and multifaceted. In support of the robustness of the phenomenon, PoP occurred in every condition across all experiments (i.e., even when either or both of the latter components of the typical paradigm were omitted). However, removing any component from the paradigm reduced the magnitude of PoP compared to the typical task, so what is traditionally viewed as PoP has dissociable components. Theoretical implications for PoP and the interaction between action and perception more broadly are discussed.

Chapter 1: Introduction

Many tasks in daily life—for example, looking for one’s keys on a cluttered office desk—require visual search—that is, searching for a target amongst non-target items. There are many factors that can influence where one’s attention is drawn first in a scene when conducting such a search. For example, considerable research illustrates how an observer’s goals can influence their attention (e.g., Folk, Remington, & Johnston, 1992). So, for example, if your keychain is red, you might be more likely to accidentally look towards a red pen rather than a blue mug while searching for your keys. In addition, it is widely documented that attention is drawn to salient (i.e., uniquely colored or shaped) items in a scene (e.g., Theeuwes, 2004); thus if your keychain is the only red item on the desk it would be easier to find than if there were multiple red items. Furthermore, it has been known for some time that features that were previously attended to, or were behaviorally important, can influence where attention is allocated in a visual scene. This mechanism of selection—the effects of the past on current vision—is the focus of the present dissertation. Specifically, the phenomenon of interest occurs when observers are faster to find a target in a visual search if it shares a feature (i.e., color) with an earlier search target, even if that target might otherwise stand out due to physical salience (e.g., Maljkovic & Nakayama, 1994). The phenomenon, known as *Priming of Pop Out* (PoP) has been researched extensively over the past 20 years, and plays an important role in some recent frameworks of attentional control (e.g., Awh, Belopolsky, & Theeuwes, 2012).

Concurrently, a growing body of research has examined the role of action in perception. It is both intuitively obvious and has been empirically documented for over a century (e.g., Woodworth, 1899) that perception influences action – for example, consider the difficulty of finding a light switch in the dark compared to in a light room. However, only more recently has research highlighted the many facets of the inverse relationship of action influencing perception. Most relevant to this dissertation, are findings revealing that simply making an arbitrary response to a stimulus can also have an effect on subsequent visual search performance– features of acted on objects receive priority even if they are irrelevant to the current task (e.g., Weidler & Abrams, 2014; *the action effect*). As will be detailed later, the role of action in PoP has yet to be thoroughly explored. This dissertation aims to investigate the relationship between PoP and the action effect to expand our knowledge – both about the critical factors necessary for PoP and ways in which simple action can affect perception. More broadly, this will provide insight into understanding how the actions people make influence how they selectively allocate their attention to certain items amongst others, an activity which is crucial for daily life.

1.1 Priming of Pop Out in Visual Search

In the first study of PoP, Maljkovic and Nakayama (1994) aimed to discover the mechanism behind the earlier findings of Bravo and Nakayama (1992). Bravo and Nakayama presented participants with search arrays of notched diamonds (one side of the diamond was missing); each array contained a single diamond with a unique color (see Figure 1 for an example of such a display). Participants were asked to find the uniquely colored diamond and indicate the side of its notch under two conditions – in the *blocked* condition the unique target color was known on every trial (e.g., it was always red amongst green distractors) whereas in the *mixed* condition the target's color varied unpredictably from trial to trial. Bravo and Nakayama

found a large response time difference between the blocked and mixed conditions – participants were dramatically faster in the blocked condition than in the face of target color unpredictability during the mixed condition.

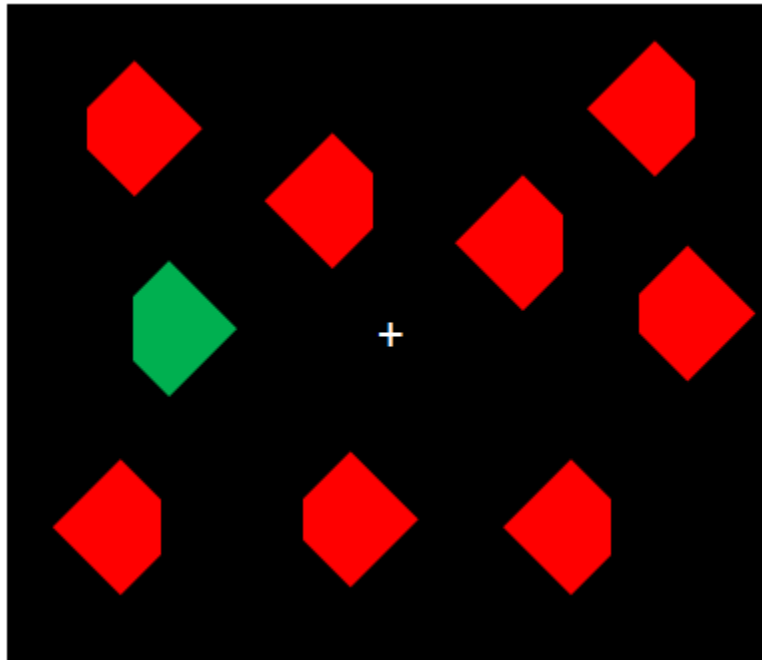


Figure 1. Example display of multiple notched diamonds, similar to those used in Bravo and Nakayama (1992) and Maljkovic and Nakayama (1994).

Maljkovic and Nakayama (1994) argued there could be two explanations for the improved performance in the blocked condition. First, participants' knowledge about the nature of the target could be improving their performance—in the blocked condition one can predict perfectly the color of the next target and perhaps that knowledge allows for preparation that speeds performance. Alternatively, humans may possess a brief memory system that facilitates performance when the target shares features with those that were previously behaviorally important.

To distinguish between these two possibilities, Maljkovic and Nakayama (1994) manipulated the probability that the color of the target would switch on the upcoming trial. For

example, in one block of trials the probability of a switch might be 0 (so the target color remained constant for that block) and in another the probability of a switch might be 1 (the target color switched on *every* trial). Importantly, the amount of information about the target color in these two situations is identical when there are only two possible colors – with two stimulus colors the participant can always perfectly predict the color of the target on the next trial. Therefore, if observers’ expectations (knowledge) about the upcoming target were guiding the observed priming effects, one would expect response times to be roughly equivalent when the probability of a switch is 0 or 1. Alternatively, if the system driving priming is a brief form of memory for the previous target’s features, performance would be dependent on the extent to which the current target shares a color with the previous target. Thus response times should be slower when the target color switches on every trial (Maljkovic & Nakayama, 1994).

Supporting the idea of a short term memory system causing priming, response times were much slower when the target color switched on every trial than when it stayed the same (Maljkovic & Nakayama, 1994). Additionally, in support of the unconscious or automatic nature of the priming, the effect did not seem to depend on active preparation for the target. In another experiment in which the color was completely predictable (i.e., it alternated in an AABB sequence), in one condition the researchers asked participants to sub-vocally prepare for the upcoming target (e.g., say “red” or “green” to themselves at the appropriate time). and this manipulation did not affect the magnitude of priming (Maljkovic & Nakayama, 1994).

Thus, in the first investigation of PoP, Maljkovic and Nakayama (1994) illustrated the implicit and involuntary aspect of priming, which is still believed to be a defining feature of PoP (e.g., Kristjansson & Campana, 2010). In addition, their paradigm has remained popular and a modified version will be used in the current dissertation. In this paradigm (which will be referred

to as the *typical* paradigm throughout the dissertation) on each trial, after a variable duration fixation cross, participants are presented with a search display containing numerous notched diamonds (recall that this is a diamond with its right or left corner missing). One of the diamonds always has a unique color amongst all like-colored distractors, however the participants do not know the target color in advance. A participant's task is to identify the location of the notch of the uniquely colored target as quickly as possible. Priming is measured evaluating response time (or less frequently accuracy) in the current trial as a function of color repetition from the preceding trial (i.e., whether the target color *repeats* or *switches* from the preceding trial). PoP occurs if response times are faster when the current target's color is the same as the previous trial's target color than when the colors switch¹.

Importantly for the current dissertation, the typical PoP paradigm can be divided into three components. First, participants must view the stimulus array (hereafter referred to as the "View stimuli" component). Second, participants must allocate spatial attention (cf. Bravo & Nakayama, 1992) to the correct target element to identify the location of its notch (hereafter referred to as the "Locate target" component). Third, participants must make the correct motor response (hereafter referred to as the "Make response" component). These components have not yet been fully disentangled in prior research; the present research will help to clarify the role of each of these stages in PoP.

Although the present dissertation will focus on color priming in pop-out search, I note the established pervasiveness of PoP with other stimuli and tasks. First, PoP in visual search occurs

¹ A reader may be curious about the terminology of "switch". In the research discussed by Maljkovic and Nakayama (1994) and in the current dissertation there will only be two colors used for the visual search task. Thus, the term switch is used because when the target color changes from trial n-1 to trial n, on trial n the target's color will be that of the distractors from trial n-1. Research has indicated that both target facilitation and distractor inhibition contribute to PoP in the situation where targets and distractors switch (e.g., Lamy, Antebi, Aviani, & Carmel, 2008), so PoP is the largest in the case where there are only two possible colors involved in the task.

across many perceptual dimensions. In addition to extensive evidence indicating that color can be primed (e.g., Asgeirsson, Kristjánsson, & Bundesen, 2014; Kristjánsson, 2009; Maljkovic & Nakayama, 1994; McBride, Leonards, & Gilchrist, 2009), further research has revealed that other dimensions such as spatial frequency and orientation can be primed (e.g., Kristjánsson, 2006). In addition, there is evidence that spatial dimensions such as location (e.g., Maljkovic & Nakayama, 1996; Asgeirsson et al., 2014) and even motion direction (Kristjánsson, 2009) can be primed. In addition, priming occurs across many tasks. Although the present investigation focuses on priming of *pop-out* search, facilitation of search when features of the prior target match the current target (i.e., priming) can occur in conjunction searches (e.g., Hillstrom, 2000) as well as present-absent tasks (e.g., Olivers & Meeters, 2006).

1.2 Action and Perception Research

Recent research has highlighted the important role of action in human perception. There are many facets to this relationship. For example, the action-specific account of perception argues that individuals' momentary ability to interact with the world influences perception (e.g., Witt, 2011). This theory accounts for results illustrating that participants who are physically encumbered (e.g., wearing a heavy backpack) or energy depleted (e.g., just completed exhausting exercise) perceive hill slants to be greater than participants who are unencumbered or rested (e.g., Bhalla & Proffitt, 1999); in the former states it would be more difficult to interact with (i.e., climb) the hill so it is perceived as steeper. In addition, related research shows that preparing a certain specific motor action can affect perception. For example, Wykowska, Schubö, and Hommel (2009) asked participants to search for size or luminance singletons amongst an array of like-size or like-brightness distractors. Prior to the search, participants either prepared a pointing or a grasping motion. The researchers found that participants indicated the presence/absence of

size singletons faster when they were preparing a grasping motion compared to when they prepared a pointing motion. This result presumably occurs because size is relevant for a grasping motion, thus the perceptual system was particularly tuned to the size dimension when a grasping motion was prepared.

Importantly to the current dissertation, recent research has also revealed that just making a simple action (a key press) in the presence of a visual object can alter subsequent perception of other items that share that object's features (e.g., its color). In the first demonstration of this phenomenon, on each trial participants saw a color word (e.g., "yellow") followed by a colored shape (Buttaccio & Hahn, 2011). If the color word matched the color of the shape (e.g., the shape was colored yellow) participants were to press a button as quickly as possible (i.e., make an action). If the color word and the color of the shape did not match, participants did nothing (this is the *action task*). Then, on every trial, participants performed an ostensibly unrelated visual *search task* for a tilted line among vertical distractor lines, and indicated the direction of tilt.

Despite color being irrelevant to the search task, the authors manipulated the location of the color of the object from the action task relative to the target in the search task: on valid trials the tilted target line was in the color seen during the action task, and on invalid trials that color contained a vertical distractor. Buttaccio and Hahn (2011) found that validity had a strong effect on search RTs (valid faster than invalid), but *only* following an action. When participants were just exposed to the color but did not act in response to it, RTs did not differ based on whether that color contained a target or distractor during the search task. Thus, the *action effect* reveals that perception is biased towards features (color in this case) that just received an action.

Subsequently, research has further established the reliability and pervasiveness of this effect. For example, the action effect still occurs when participants need not process *any* feature

of the object presented during the action task. More specifically, Weidler and Abrams (2014) pre-cued participants with the word “GO” or “NO” during the action task; participants were instructed if they saw the word GO to press a button as quickly as possible when the next object appeared and if they saw the word NO to merely view the next object that appeared. The search task was similar to that of Buttaccio and Hahn (2011; i.e., participants looked for the sole tilted line and indicated its orientation). Even in this case, when participants were not required to process any properties of the action object and the manipulated feature (color) had nothing to do with any part of the experimental task, there was still evidence for the action effect. In addition, research has revealed that the effect does not rely on the visual consequence of the action. More specifically, in the experiments just described, the action condition also included a “visual consequence” – the prime disappeared immediately upon action. However, the action effect is still reliable and of the same magnitude when there is no visual consequence upon response (i.e., if the circle remains present for the same duration in action and non-action trials regardless of the time of the button press; Weidler & Abrams, 2014).

In addition, the action effect is not limited to color; simple action can alter subsequent perception of shape information as well (Weidler & Abrams, 2017a). Furthermore, in support of the pervasiveness of the effect, it seems that action can also alter conceptual relationships. More specifically, participants responded more quickly to a target in a visual search task that was superimposed on a picture that represented a *word* to which they previously acted (Weidler & Abrams, 2017b).

Finally, research about how action affects subsequent perception has implicated action as a factor that can affect perception even when the target is a salient singleton. This experiment was similar to a typical action effect experiment: Participants were pre-cued with the word GO

or NO, saw an object (and made an action following a “GO” pre-cue), then performed a visual search task. Importantly, in the search task, instead of looking for the sole tilted line, participants were asked to locate the uniquely colored target and indicate the tilt of its line (all lines in the search array were tilted). Despite the fact that the target was a perceptual singleton on each trial that should presumably capture attention easily (e.g., Treisman, 1988), there was still evidence for the action effect: Following an action participants responded more quickly on valid than invalid trials, whereas after merely viewing the display there was no effect of validity (Weidler & Abrams, 2017c).

1.3 Interim Summary: Implications of Action and Perception Research for PoP

In summary, recent research has revealed that simple, arbitrary actions can reliably affect subsequent perception of different types of stimuli (color and shape; e.g., Buttaccio & Hahn, 2011; Weidler & Abrams, 2014b) in a variety of search tasks (serial or pop-out; e.g., Weidler & Abrams, 2014, 2017c), even when the features of the object are irrelevant to the task (e.g., Weidler & Abrams, 2014). Together these results imply that action may be an important and under-considered element in perceptual paradigms that require manual responses and investigate the effects of the past on subsequent perception, such as the typical PoP paradigm (e.g., Maljkovic & Nakayama, 1994). Recall that PoP specifically investigates how events in the past affect current perception. More specifically, the typical analysis examines performance on trial n as a function of the relationship between the target’s features on trial $n-1$ and that of the current trial’s (i.e., whether it switches or repeats). Importantly, a response is always made on trial $n-1$ in the typical PoP paradigm (e.g., Maljkovic & Nakayama, 1994). Given the recently discussed

effects of action on perception it certainly seems plausible that action could be playing an important role in PoP. As described below, PoP researchers have begun to investigate this question, and the goal of this dissertation is to provide a full scope of the role of action in PoP.

1.4 The Role of Action in PoP

Although this dissertation is the first to fully explore the role of action in PoP, two recent investigations have provided data relevant to the topic. In the first, Kristjansson, Saevarsson, and Driver (2013) aimed to follow-up on recent findings suggesting that PoP may be driven by attentional choice (i.e., allocating focal attention to the target to discriminate the side of the target's notch) on trial $n-1$ (Brascamp, Blake, & Kristjansson, 2011). If attentional choice is *necessary* for priming, Kristjansson et al. reasoned that there should be no PoP following trials in which participants are not actively required to search the display. In order to investigate this, Kristjansson et al. showed participants typical PoP displays containing one color singleton and two like-colored distractors, and they pre-cued participants on a trial-by-trial basis to perform either the *active* or *passive* task. On active trials participants engaged in the typical PoP task (find the uniquely colored diamond and indicate the location of its notch), whereas on passive trials participants merely viewed the display until it self-terminated. Kristjansson et al. examined performance on the active trials as a function of whether that trial was preceded by an active or passive trial (and also as a function of whether the target color repeated or switched; i.e., the typical independent variable in PoP investigations). Although the researchers obtained the typical PoP effect of faster RTs for color repetition than color switch trials if the prior trial had been an active trial, Kristjansson et al. found no PoP after passive trials. This suggests that action may be required to obtain PoP and has implications for the present dissertation aiming to investigate the role of action in PoP.

However, a subsequent investigation by Yashar, Makovski, and Lamy (2013) found a different pattern of results using a similar paradigm. On each trial, participants were pre-cued to either view a display of five notched diamonds (one uniquely colored target and four like-colored distractors) or to perform the typical PoP task (find the uniquely colored diamond and the location of its notch). Contrary to Kristjansson et al. (2013), Yashar et al. found priming after both viewing and performing the typical task, although the magnitude of PoP following trials in which there was no action was reliably reduced. In addition, the authors conducted a second experiment that incorporated two methodological changes to ensure that participants were not preparing a motor response on the passive viewing trials. First, the authors intermixed active and passive trials in a predictable ABAB pattern in order to reduce any confusion regarding the pre-cue that might have resulted in participants preparing a response on a every trial (the task was randomly selected on a trial-by-trial basis in their first experiment). Second, the authors reduced the duration of the passive viewing trials to 250 ms, arguing that under these conditions there would be no time to prepare a response while the stimuli were present. Even with these methodological changes, Yashar et al. found evidence for priming following passive viewing (i.e., PoP after trials with no action). Thus, these results imply that PoP can occur after passive viewing; if this is true then action may not be necessary to obtain PoP.

1.5 Goals of Dissertation

The goal of this dissertation is to fully elucidate the role of action in PoP. As discussed earlier, the processes involved in the typical PoP task can be subdivided into three primary components – viewing the stimuli, locating the target’s response-defining feature, and making the appropriate motor response. In most PoP research, participants engage in all three of these components on each trial. Furthermore, in daily tasks that rely on the mechanisms of PoP,

observers would engage in all three of these stages. For example, when foraging for food, individuals might see many berries of varying ripeness. Then attention might be drawn to a unique berry based on its defining characteristics (i.e., its unique color) as well as the individual's top down goal of finding sustenance. Then, the individual must make an appropriate action towards the item to achieve their goal. In order to gain more insight into the role of each of these processes, they can be experimentally dissociated in the laboratory. Examining how each of these components affects PoP is the topic of this dissertation. The three experiments in this dissertation isolate the role of the latter two components (the motor response and target locating processes Experiments 2 and 3, respectively), and examine whether PoP can occur after passive viewing (the first component) of the stimuli (Experiment 1) in order to understand the full role of action and target localization in PoP. In order to accomplish this goal, in each experiment an "atypical" task was interspersed with the "typical" PoP task. The atypical task always omitted a component or components of the typical PoP task. Figure 2 shows a schematic of the components in the typical PoP paradigm, as well as which task will additionally be included with the typical paradigm in each experiment.

	Component of Task			
	1) View stimuli	2) Locate target	3) Make response	
Typical PoP Paradigm (included in all experiments)	✓	✓	✓	
<i>Atypical task intermixed with typical paradigm:</i>				Allows isolation of which component?
Experiment 1	✓			NA – two differ
Experiment 2	✓	✓		Making response
Experiment 3	✓		✓	Target localization

Figure 2. The first row depicts the components involved in the typical PoP paradigm. The bottom three rows depict the atypical condition that was interspersed with typical PoP trials in Experiments 1-3 to examine how the removal of certain components affects PoP. For example, to examine if action (the motor response) contributes uniquely to PoP (Experiment 2), the effect when a trial without a motor response precedes the typical trial will be compared to the case in which a typical trial precedes a typical trial (see Experiment 2 method for more detail).

As an overview, on every trial in each experiment participants were randomly pre-cued to perform one of two tasks: (1) the typical PoP task or (2) the atypical “experimental condition” depicted in the bottom three rows of Figure 1. Then in each experiment, performance on the typical task trials was analyzed as a function of the type of task that preceded it (typical or atypical), as well as the match between the current and previous trial’s target color (the traditional PoP analysis; e.g., Maljkovic and Nakayama, 1994). In the sections below I first describe the broad theoretical goals of each experiment, and then subsequently detail the methods for each.

1. 5. 1 Goals of Experiment 1

The previous section highlighted two recent studies that compared a condition in which participants passively viewed the display to a condition in which participants completed the typical PoP task (Kristjansson et al., 2013; Yashar et al., 2013). However, these studies provided discrepant results – while Kristjansson et al. found no priming following passive viewing, Yashar et al. found reliable PoP in their comparable task. The goal of Experiment 1 is to conceptually replicate these experiments and address a factor that may have contributed to the discrepant results. Specifically, Kristjansson et al. used displays containing three items whereas Yashar et al.’s displays contained five items. Importantly, prior research has indicated that in conditions very similar to the typical PoP paradigm the number of elements in the search array affects performance (e.g., Bravo & Nakayama, 1992; Maljkovic & Nakayama, 1994; more detail is provided in the introduction to Experiment 1). Therefore, in addition to conceptually replicating previous work, Experiment 1 employs a display-size manipulation to investigate if this factor may have contributed to the divergent findings in the earlier studies. If the display-size difference in prior work truly is a factor that influences whether PoP occurs following passive viewing, then PoP following passive viewing may only be present, or increased in magnitude at the larger display size (cf. Yashar et al., 2013).

1. 5. 2. Goals of Experiment 2

Irrespective of the outcome of Experiment 1, there is another open issue involving the role action plays in PoP. Although Kristjansson et al. (2013) and Yashar et al. (2013) investigated if motor response is *necessary* to obtain PoP, neither study completely isolated the effect of motor response in PoP. Specifically, both prior investigations compared a case in which participants only viewed the stimuli to the typical task in which participants viewed the

stimuli, attended to the target, and responded. Therefore, both finding the target and making a response were confounded in that prior research. Experiment 2 examines if the motor response specifically contributes a unique component to PoP in when participants still are required to attend to the target. In order to isolate the role of motor response in PoP, Experiment 2 compares a condition in which participants perform the typical PoP task to a condition in which participants view the stimuli *and* find the target but do not make a response (see Figure 2). If a motor response indeed exerts a unique effect on PoP, then there should be greater PoP in the typical trials following the trials on which a motor response is executed (i.e., another typical trial) than following trials not containing a motor response (i.e., those just encompassing components 1 and 2 of the PoP paradigm; see Figure 2).

1. 5. 3. Goals of Experiment 3

The goal of Experiment 3 is to isolate the role of the target localization component in PoP. In order to investigate this question, Experiment 3 will assess if a simple arbitrary action (e.g., not relevant to any feature of the stimuli) is sufficient for producing PoP. This will be accomplished by interspersing the typical PoP task with trials in which participants are pre-cued to press a key as soon as the display appears, regardless of any of the display contents. Research on the action effect has revealed that prior action can modulate performance in a pop-out visual search task (Weidler & Abrams, 2017c). Therefore, it may be possible that an arbitrary pre-cued action can create the typical magnitude of PoP. However, some researchers have argued that allocating attention to the target (i.e., finding the target) in trial n-1 is critical to obtain PoP in trial n (e.g., Kristjansson et al., 2013). Therefore, given that the locate target component (the component when focal attention is allocated towards the target; cf. e.g., Bravo & Nakayama,

1992) is missing from the atypical condition in Experiment 3 (see Figure 2), PoP may be reduced or absent following an arbitrary action.

Chapter 2: Experiment 1

2.1 Introduction

Is PoP obtained following passive viewing of a display containing a uniquely colored element? Two recent studies that investigated this question produced discrepant results. However, there may be a difference in their methods that led to the divergent results. More specifically, the researchers who found no effect of priming following passive trials used a display size of three items (Kristjánsson et al., 2013) whereas the research that found priming following passive trials used a display size of five items (Yashar et al., 2013). Prior research indicates that this display-size discrepancy may be important. Specifically, Bravo and Nakayama (1992; see also Maljkovic & Nakayama, 1994) asked participants to indicate the location of a notch on a uniquely colored item amongst multiple like-colored distractors. When the target feature was unpredictable (i.e., participants did not know *which* unique color the target would be; as in the typical PoP paradigm), RTs decreased with increasing display size. Importantly, the mechanism that improved performance in this scenario is thought to (a) specifically facilitate allocation of attention to the uniquely colored target and (b) be a bottom up mechanism—or controlled by the stimuli instead of the observers' goals (e.g., Treisman, 1988). Thus, although on the passive trials in prior research participants' task did not require them to look towards the uniquely colored element, perhaps bottom-up mechanisms may have allocated attention to that item more strongly when a larger display size was used (e.g., in Yashar et al., 2013) than when a smaller display size was used (e.g., in Kristjánsson et al., 2013). The present experiment directly manipulated display size in order to investigate if perhaps PoP can occur after passive viewing, but only with a larger display size.

2.2 Method

2.2.1 Participants

Forty undergraduates with normal or corrected to normal vision and color vision participated (N = 20 at each of two display-sizes).

2.2.2. Apparatus

Participants viewed stimuli on a CRT monitor with a refresh rate of 85 hz from approximately 48 cm. The experiment was programmed with Psychopy (Peirce, 2007).

2.2.3. Stimuli and Procedure.

There were two general phases in this experiment—the *typical PoP* phase and the *look/typical* phase. See Figure 3 for an example trial of the typical phase. Each trial in the typical phase began with a white, centrally presented fixation cross (1° in height) for 1000, 1200, or 1400 ms. This was followed by a search array containing three or six (each subject only saw one display size) elements. Each element was a green or red diamond (a square 3° in height and 3° , rotated 45 degrees) with a notch missing from either its left or right side (the notch removed $.62^\circ$ of visual angle from the diamond's corner). The participants' task was to find the uniquely colored element and indicate the location of its notch by pressing the left or right arrow key on a keyboard. Each element remained on screen for 1200 ms or until response. Each trial was followed by a 1000 ms inter-trial-interval that contained 506 ms of auditory (an 80 hz beep) and visual feedback if the trial was incorrect or too slow.

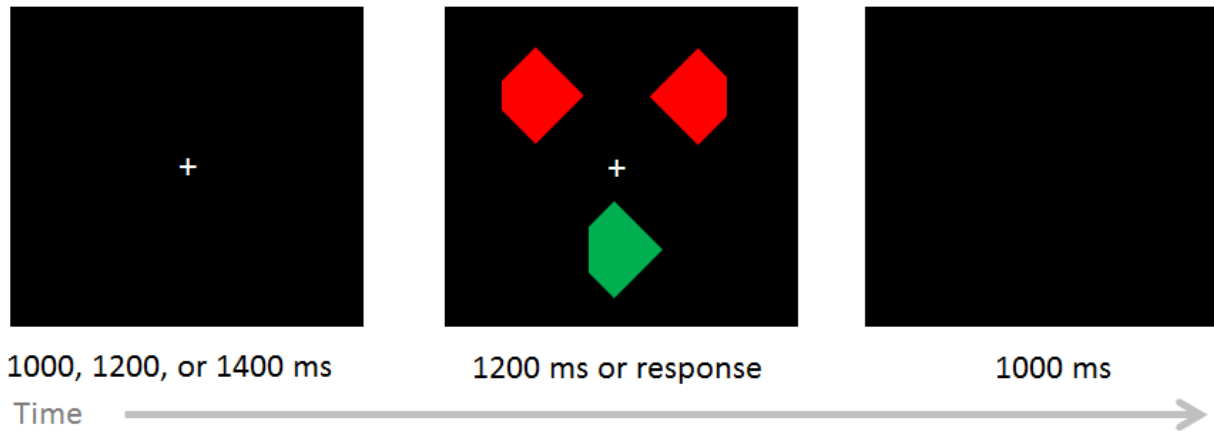


Figure 3. Method for the typical phase of Experiment 1. Note that display size 3 is depicted, but half of the participants experienced display size 6 (in which there were five distractors on each trial). Figure is not drawn to scale.

After completing the typical phase, participants completed the look/typical phase (see Figure 4 for a depiction of the sequence of events). The method was the same as in the typical phase with the following exceptions. During the first 506 ms of the fixation cross display the word “NOTCH” or “LOOK” (2° in height, white) was presented 2° above fixation. Next, the same search array as during the typical phase appeared. If participants had previously seen the word “NOTCH”, they looked for the uniquely colored shape and indicated the side of its notch (e.g., performed the same exact task as during the typical phase). If participants had previously seen the word “LOOK” they just viewed the display until it disappeared (after 800 ms).

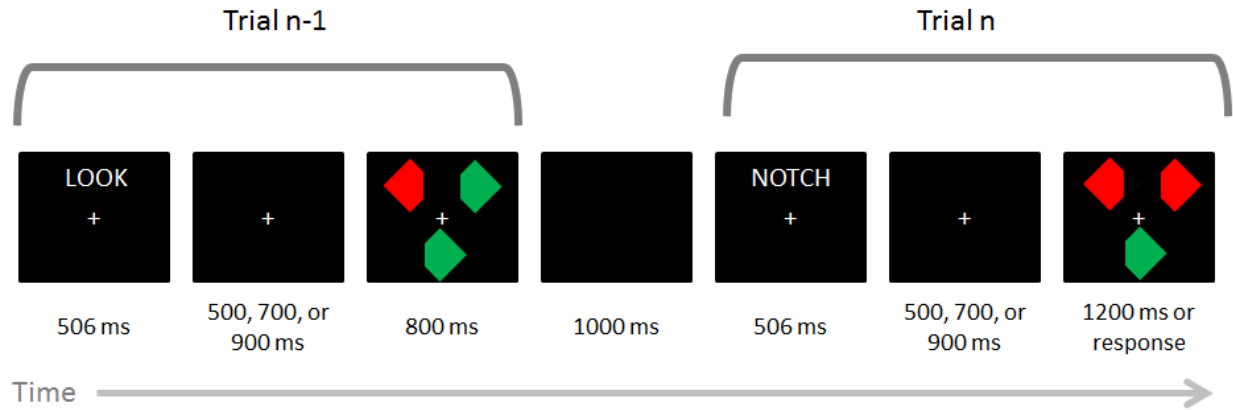


Figure 4. Example trial sequence from the look/typical phase of Experiment 1. This represents an atypical trial followed by the typical trial, and the target color switches between trials.

2.2.4. Design

The typical PoP phase had a 2 (display size: 3 or 6) x 2 color repetition (repeat or switch) mixed design (with display size as the between-participants factor). Note that the independent variable of color repetition refers to whether the target color of the current trial repeats or switched from that of the previous trial, regardless of the actual color of the stimuli. After 24 practice trials (which were not included in the analysis) participants completed three blocks of 60 trials each, with a self-paced break between each block, for a total of 180 test trials. Each 60-trial block was composed of a base of six unique trials (2 target colors x 3 fixation durations) repeated 10 times.

The look/typical phase had a 2 (display size: 3 or 6) x 2 (task: look or typical²; see footnote for note about terminology) x 2 color repetition (repeat or switch) mixed design (with display size as the between participants factor). Participants completed 24 practice trials followed by nine test blocks of 60 trials each. Each 60-trial test block was composed of a base of

² Although the word cuing the subject was “NOTCH”, when describing the design and analyses I will refer to the task in which participants indicated the location of the notch on the uniquely colored diamond as the “Typical” task throughout the dissertation.

12 trials (2 task cue x 2 target color x 3 fixation duration) repeated five times. Participants received a break after each block.

There were six potential locations on the screen that could contain a target or a distractor. On display size 6 trials, all positions were occupied, with the target's location chosen randomly from the six. On display size 3 trials, the items occupied three locations while remaining equidistant from each other. Once a display of three equidistant locations was randomly selected, the target's location was chosen at random from the three. The locations of the notches on the target and each of the distractors were chosen randomly on each trial.

2.3 Results

The first trial of every block and trials following errors were excluded from all analyses. Error trials were additionally excluded from the RT analyses.

2.3.1 Typical Phase

A 2 (display: size 3 or 6) x 2 (color repetition: repeat or switch) mixed ANOVA (with display size as the between subjects factor) on RT revealed a main effect of display size, $F(1,38) = 20.22, p < .001, \eta^2_p = .35$, and a main effect of target color repetition, $F(1,38) = 260.69, p < .001, \eta^2_p = .87$. Participants responded more quickly in display-size 6 trials ($M = 609$) than display-size 3 trials ($M = 682$), and more quickly in color repeat ($M = 621$ ms) than color switch trials ($M = 670$ ms). There was no interaction between the two factors, $F(1,38) = 1.14, p = .293$ (see Figure 5), as the PoP effect (i.e., the main effect of target color repetition) was similarly sized in display size 3 (52 ms) and display size 6 (46 ms).

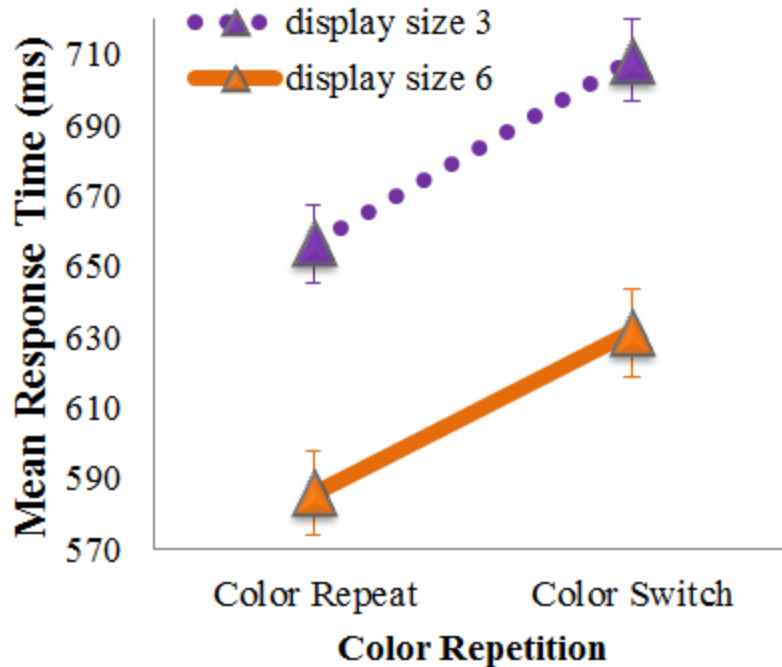


Figure 5. Data from the typical phase of Experiment 1 as a function of display size and target color repetition. There was a main effect of both independent variables (participants were faster at the larger display size and when the target color repeated). Error bars represent standard errors of the mean.

The same 2x2 mixed ANOVA on accuracy data revealed a marginally reliable main effect of target color repetition, $F(1,38) = 3.58, p = .066, \eta^2_p = .09$, with better performance on color repeat (97.8%) than color switch (97.0%) trials. In addition, there was a marginally reliable main effect of display size, $F(1,38) = 4.01, p = .052, \eta^2_p = .10$, with participants who searched six items performing better than participants who searched three items ($M_{\text{three}} = 96.5\%, M_{\text{six}} = 98.2\%$). The factors did not interact, $F < 1$ (see Table 1 for accuracy data).

Table 1

Accuracy (percent correct) in the Typical Phase of Experiment 1 (SE in parentheses)

Display Size	Color Repetition	Accuracy (SE)
Three	Repeat	96.85 (.32)
	Switch	96.18 (.64)
Six	Repeat	98.70 (.39)
	Switch	97.76 (.54)

2.3.2 Look/Typical Phase

Response times from the typical trials in the look/typical phase were analyzed with a 2 (display size: 3 or 6) x 2 (prior task: Typical or Look) x 2 target color repetition (repeated or switched) mixed ANOVA (with display size as a between-subjects factor; recall that there was no RT to analyze from look trials), and can be seen in Figure 6. The analysis revealed a reliable main effect of each factor. Participants seeing six stimuli responded more quickly ($M = 584$) overall than participants searching three ($M = 633$), $F(1,38) = 11.20$, $p = .002$, $\eta^2_p = .23$. In addition, there was a main effect of prior task, $F(1,38) = 32.66$, $p < .001$, $\eta^2_p = .46$, with faster responding following look trials ($M = 603$ ms) than following typical trials ($M = 614$ ms). There was also a main effect of target color repetition, $F(1,38) = 164.28$, $p < .001$, $\eta^2_p = .81$, with faster responding when the color repeated ($M = 591$ ms) than when it switched, ($M = 626$ ms), resulting in an overall PoP effect of 35 ms.

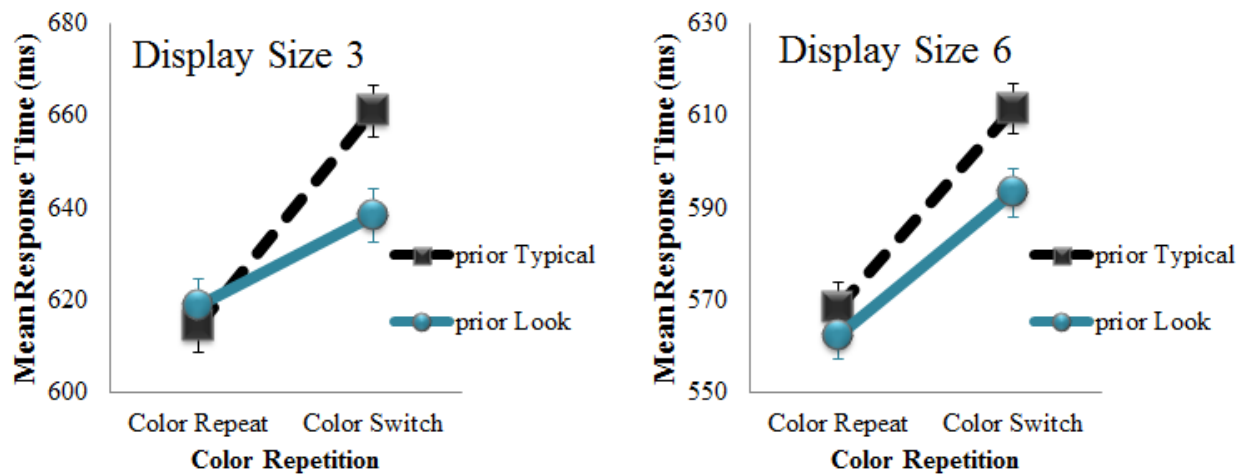


Figure 6. Data from the typical trials in the look/typical phase of Experiment 1 as a function of display size, prior trial type, and target color repetition. The difference in PoP following look and typical trials was smaller in display size 6. This was primarily driven by a smaller reduction in PoP following look trials in display size 6 compared to display size 3. Error bars show 95% within-subjects confidence intervals.

In addition, there was prior task by target color interaction, $F(1,38) = 27.53, p < .001, \eta^2_p = .42$, that was (marginally) modulated by display size, $F(1,38) = 3.90, p = .056, \eta^2_p = .09$ (see Figure 6). The two-way interaction arose because the PoP effect was larger following a typical trial (45 ms) than following a look trial (25 ms). Follow up 2 prior task x 2 target color analyses within each display size revealed that the two-way interaction was reliable in display size 6, $F(1,38) = 5.75, p = .027, \eta^2_p = .23$, as well as display size 3, $F(1,38) = 24.30, p < .001, \eta^2_p = .56$; the three-way interaction arose because the reduction in PoP following look compared to typical trials was greater in display size 3 compared to display size 6. More specifically, the three-way interaction seemed to arise from a difference in PoP following look trials between display sizes. In a 2 display size x 2 target color mixed ANOVA on RTs selectively from trials preceded by a look trial the interaction approached significance, $F(1,38) = 3.78, p = .059, \eta^2_p = .09$, because of greater priming following look trials in display size 6 (31 ms) than in display size 3 (20 ms). However, there was no reliable difference in the magnitude of PoP between display sizes for trials following typical trials ($M_{\text{Display Size 6}}=43$ ms, $M_{\text{Display Size 3}}=47$ ms; $F < 1$ on interaction). Finally, it should be noted that reliable PoP (all $ps < .001$ and $ts > 4$) was found in each condition at both display sizes during both phases of the experiment (see Figure 7).

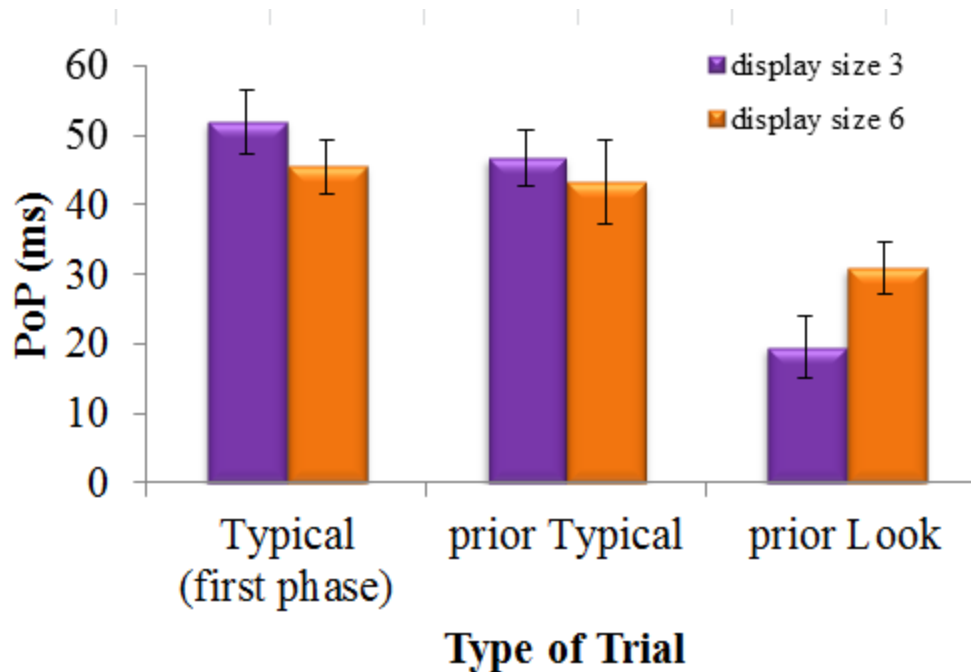


Figure 7. The magnitude of PoP (color switch RT – color repeat RT) as a function of display size in the typical stage and as a function of prior trial and display size in the look/typical phase. Error bars represent standard errors of the mean.

The same 2 display size x 2 prior task x 2 target color mixed ANOVA on accuracy revealed a main effect of prior task, $F(1,38) = 4.23, p = .047, \eta^2_p = .10$, with better performance after look trials (97.9%) than typical trials (97.1%). In addition, there was a main effect of color repetition, $F(1,38) = 6.22, p = .017, \eta^2_p = .14$, that mirrored the PoP pattern in RT with better performance on repeat (97.9%) than switch (97.1%) trials. There was no effect of display size ($F < 1$). In addition, there was a marginally reliable display size by color interaction, $F(1,38) = 3.63, p = .064, \eta^2_p = .09$. This pattern arose because the PoP effect (i.e., the effect of the target color variable) was only reliable in display size three. Indeed, when performing a 2 prior task x 2 color repetition ANOVA on data from just display-size three participants, there was a reliable effect of target color, $F(1,19) = 7.09, p = .015, \eta^2_p = .27$, with better performance overall for color repeat (98.0%) than color switch trials (96.7%). However, the same analysis on participants who saw

six items did not show a reliable effect of target color ($F < 1$). The three-way interaction did not approach significance in accuracy data, $F(1,38) = 1.21, p = .278$.

Table 2

Accuracy (percent correct) in the Look/Typical Phase of Experiment 1 (SE in parentheses)

Display Size	Prior Task	Target Color	Accuracy
Three	Typical	Repeat	97.95 (.71)
		Switch	96.33 (.79)
	Look	Repeat	97.99 (.65)
		Switch	96.98 (.67)
Six	Typical	Repeat	97.04 (.57)
		Switch	97.20 (.63)
	Look	Repeat	98.48 (.33)
		Switch	97.97 (.40)

2.4 Discussion

The goal of Experiment 1 was to (1) evaluate if PoP occurs after passive viewing and (2) examine a potential factor that might have led to discrepant results in past research (Kristjansson et al., 2013; Yashar et al., 2013). In terms of the first question, in the present experiment there was reliable PoP in all conditions, including after passive viewing at both display sizes. This is at odds with Kristjansson et al.'s (2013) research that found no PoP after passive viewing of a search array, but it is consistent with Yashar et al.'s findings of PoP after passively viewing a search array. In addition, the present investigation found that PoP was reliably reduced in magnitude following only viewing compared to following the typical task that encompassed viewing, target localization, and action, which is also consistent with the findings of Yashar et al. who found reduced PoP after viewing the display.

The present experiment also provides a potential answer as to why previous studies found discrepant results about whether PoP occurs following passive viewing. I employed a between-participants manipulation of display-size to examine if the smaller display size in the work that

found no priming following passive viewing (Kristjansson et al., 2013) may have contributed to the absence of an effect. In the present research the marginally reliable three-way interaction arising from a larger difference in PoP following viewing and typical trials in display size three than six indicates that may be the case.³ More specifically, while the PoP effect following a typical trial was equivalent across display sizes, the PoP effect following viewing was marginally reliably smaller in display size 3 compared to display size 6. Thus, it seems plausible that a reason that Yashar et al. found PoP following passive viewing and Kristjansson et al. did not might be because Kristjansson et al. used a smaller display size. However, it should be noted that the smaller display size in the present experiment (three items) was the same as the display-size Kristjansson et al. used. Thus, if display-size was all that influenced PoP following passive viewing, it is not clear why Kristjansson et al. did not find evidence for such in their investigation while I did.

There are some other differences between the present work and Kristjansson et al.'s (2013) that may have contributed to the finding of PoP after passive viewing and their lack of such an effect. First, Yashar et al. (2013) suggested that perhaps Kristjansson et al.'s paradigm elicited PoP effects too small to permit detection of the expected reduced PoP following look trials. Indeed, Kristjansson et al.'s PoP effect of 25 ms (according to Yashar et al.) following "active" trials (i.e., the typical trial) is numerically smaller than the 47 ms effect found in the comparable condition in the present experiment. Another difference is that Kristjansson et al. used two different color sets across blocks (i.e., the stimuli were red and green in one block and blue and yellow in the next), whereas the present experiment and Yashar et al. used two colors consistently throughout the experiment. As mentioned earlier, PoP tends to be the strongest

³See Appendix A for analyses of an additional variable sometimes considered in PoP analyses – target shape repetition – that modulates this relationship.

when the target and distractors switch from trial to trial (e.g., Lamy et al., 2008). While this would have been true in Kristjansson et al.'s method, perhaps switching color sets between blocks reduced overall PoP effects. Another difference between the two investigations is that while I used a cue that explicitly dictated which task to perform (the word "LOOK" or "NOTCH"), Kristjansson et al. used a symbolic color-based cue (the color of a ring around the stimuli) that remained present during the visual search task (or viewing of the display). Therefore, it is possible that the requirement to recall the task rule from a color-based cue reduced the effect of PoP following passive viewing. Further research will be necessary to disentangle these possibilities.

Chapter 3: Experiment 2

3.1 Introduction

Experiment 1 investigated if PoP can be obtained after passive viewing of the stimuli. In contrast, Experiment 2 aimed to fully isolate the role of the motor response in priming to see if, given past research showing the effects of action on visual search (e.g., Buttaccio & Hahn, 2011), a motor response will contribute anything unique to the priming. Stated another way, when *only* the motor component is removed from the task, will PoP be reduced? To investigate this question, on some trials in Experiment 2 participants viewed a typical PoP search array *and* localized the target's feature, but did not respond. These trials were interspersed with typical trials in which participants viewed the stimuli, localized the target's feature, and responded with a key press. Thus the magnitude of PoP on trials following trials without a motor response will be compared to the magnitude of PoP on trials with a motor response in order to examine how crucial the motor response is to obtaining PoP.

3.2 Method

3.2.1. Participants

Twenty undergraduates with normal or corrected-to-normal vision and color vision participated.

3.2.2. Stimuli, Apparatus, Procedure, and Design.

The method was the same as the look/typical phase of Experiment 1 unless otherwise noted (see Figure 8 for a depiction of the method). At the beginning of each trial, participants

saw either the word “LOCATE” or “RESPOND” above the fixation cross. When the three-item search array appeared, participants were instructed that on every trial they should find the uniquely colored diamond *and* to note the location of its notch. If they had seen the word “RESPOND”, they were to indicate the correct side of the notch as quickly as possible by a key press whereas after seeing the word “LOCATE” they just needed to remember the correct side until the next fixation cross appeared. Furthermore, participants were instructed that occasionally after LOCATE trials the program would pause and they would be asked to correctly indicate the side of the target’s notch (hereafter referred to as *locate probe* trials). After participants’ non-speeded response to the locate probe, the next trial began.

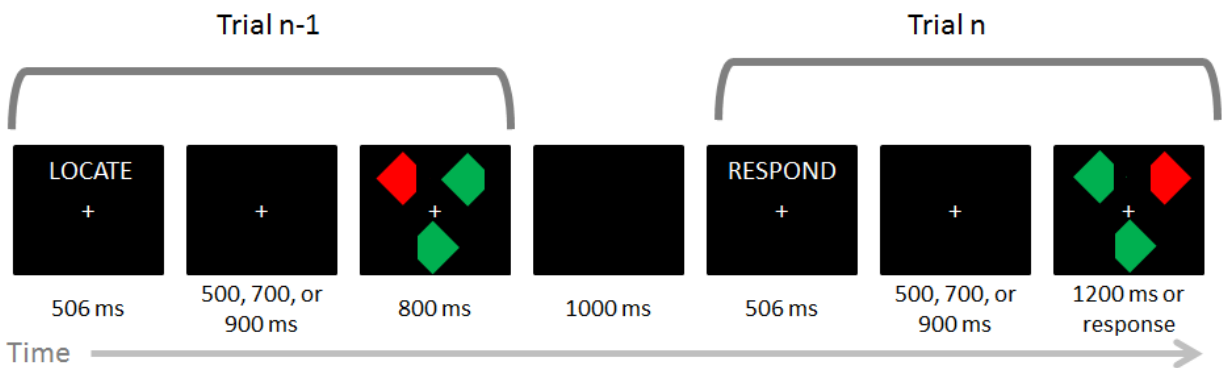


Figure 8. Example sequence of trials from Experiment 2 in which an atypical trial is followed by a typical trial and the target color repeats.

After 24 practice trials participants completed 12 blocks of 60 trials. Each 60-trial block was composed of five repetitions of 12 unique trials (2 tasks x 2 target colors x 3 fixation duration). Additionally, participants received 3 locate probe trials per block (i.e., 10% of LOCATE trials were probed). These three trials were chosen randomly from the 30 possible Locate trials in each block. The experiment had a 2 (task: Typical or Locate) x 2 (color repetition: repeat or switch) within-subjects design.

3.3 Results

Any participant who responded correctly on less than 31 out of the 36 Locate probes (< 86% accuracy) would have been replaced. However, no participant met this criterion (M probe detection = 98.3%, $SD = 2.1\%$, minimum # correct = 34). In addition to the data inclusion criteria in Experiment 1, trials after the locate probe trials were not included in the analyses.

Response times from the typical trials were analyzed with a 2 prior task (typical or locate) x 2 target color repetition (repeat or switch) within-subjects ANOVA, and can be seen in Figure 9. The analysis revealed no main effect of prior task, $F < 1$, but a reliable main effect of target color, $F(1,19) = 63.90$, $p < .001$, $\eta^2_p = .77$. This main effect arose because participants were faster on color repeat trials (613 ms) than color switch trials (661 ms; i.e., there was an overall PoP effect of 48 ms). In addition, the analysis revealed an interaction between the factors, $F(1,19) = 13.33$, $p = .002$, $\eta^2_p = .41$. This interaction arose because the magnitude of PoP was reduced following the Locate task (37 ms) compared to following the Typical task (58 ms; see Figure 9). However, there was reliable PoP both after Locate, $t(19) = 5.73$, $p < .001$, and Typical trials, $t(19) = 8.63$, $p < .001$.

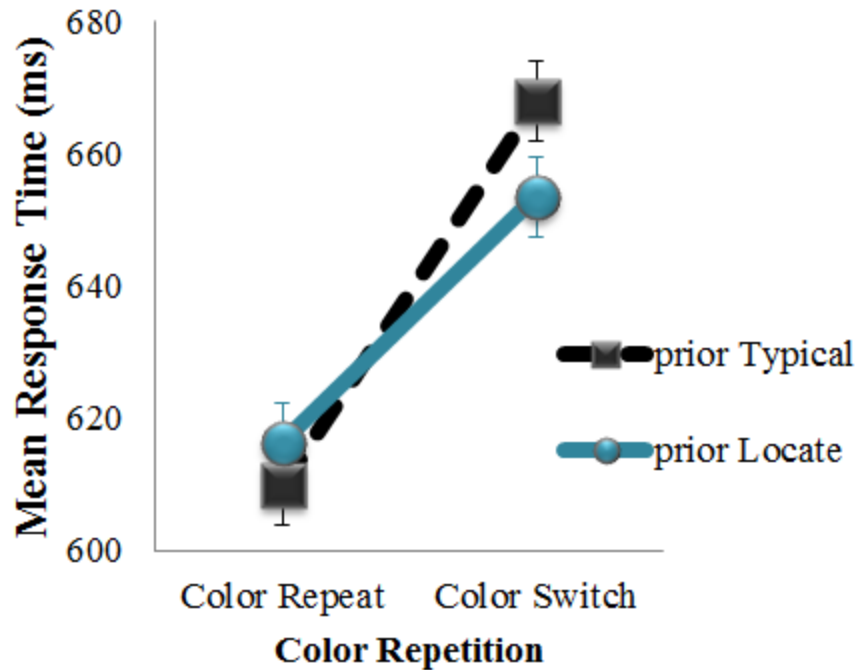


Figure 9. Response time data from Experiment 2 as a function of prior trial type and color repetition. PoP was reduced after locate trials in which there was no motor response, thus indicating that the motor response is an important stage in PoP. Error bars represent within subject 95% confidence intervals.

The same 2x2 ANOVA conducted on accuracy revealed only a reliable main effect of target color, $F(1,19) = 17.97, p < .001, \eta_p^2 = .49$, with higher accuracy on color repeat (98.0%) than color switch trials (95.9%). There was no main effect of prior task, $F(1,19) = 1.69, p = .209$, nor did the two factors interact, $F(1,19) = 1.18, p = .292$ (see Table 3 for mean accuracy by condition in Experiment 2).

Table 3
Accuracy (percent correct) in Experiment 2 (SE in parentheses)

Prior Task	Color Repetition	Accuracy (SE)
Typical	Repeat	97.92 (.32)
	Switch	95.40 (.64)
Locate	Repeat	98.13 (.39)
	Switch	96.42 (.54)

3.4 Discussion

The goal of Experiment 2 was to examine the contribution of the motor response stage to PoP. To investigate this, the present experiment included trials in which participants performed all of the stages in the PoP paradigm *except* the motor response--they viewed the display, located the uniquely colored target and made note of the side of the notch. Participants were occasionally probed about the location of the target notch after such trials and performed very well, implying compliance with the instructions. Reliable PoP was obtained after trials not containing a motor response. This is not surprising given the results of Experiment 1 – recall that there PoP was observed after merely viewing of the search display. However, the magnitude of PoP in the present experiment was reduced after trials in which no motor response was made compared to those on which a motor response was executed.

The present results imply that the motor response indeed contributes something unique to PoP above and beyond what is produced by viewing the stimuli and locating the target. Thus, these findings have implications for theories claiming a strong role of attentional localization in PoP (e.g., Kristjansson et al., 2013). That is, while the present results do not refute the importance of allocating attention to the target, the fact that there is a reduction of PoP when the motor response is eliminated implies that attentional choice alone does not account for the entire magnitude of PoP.

Additionally, the findings from the present experiment are at odds with some other recent research. Specifically, in some sequences of trials, Moher and Song (2014) were also able to examine the magnitude of PoP following a trial in which participants had located the target but not made a response, and they found no difference in PoP following those trials and following typical trials. In their research, *key press* trials were interspersed with *reaching* trials in which

participants pointed to the target; reaching versus keypress trials were cued by an image of either a keyboard or hand above the fixation cross. However, in the experiment of interest, key press trials could further be classified as *go* or *nogo* trials. After being cued for a key press trial, if the notch on the uniquely colored target diamond was on the bottom, participants were asked to make no response whereas if the notch was on the top participants were asked to respond via keypress. Thus, the manipulation on the *nogo* trials in that experiment was similar to the “LOCATE” trials in the present experiment given that participants had to view the stimuli and locate the target, but then not make a response. However, contrary to the present findings, Moher and Song found that the magnitude of PoP did not depend on whether the previous trial involved a key press response or not.

There are two important differences between the present work and that of Moher and Song (2014) that may explain the discrepant results. First, in the present experiment, participants knew they would not have to make a key press prior to the stimuli appearing on trials without a response whereas Moher and Song’s participants were unaware as to whether they needed to press a key or not prior to locating the target in the search display. Specifically, the present pre-trial cue indicated whether participants needed to perform the typical task or just locate the target and know which side its notch was on whereas Moher and Song’s pre-cue informed participants whether they needed to prepare for a reach or a keypress trial. But, on the keypress trials participants did not know whether they would execute the key press until they found the uniquely colored target and knew the response defining feature (i.e., whether the notch was on the top or bottom of the shape). Therefore, perhaps the uncertainty about whether an action would be executed until target localization lead Moher and Song to find equivalent PoP after making a keypress or not.

A second difference between the present experiment and that of Moher and Song (2014) is that they restricted eye movements (and monitored eye movements to ensure compliance), whereas free eye movements were allowed in the present research. On the surface, this methodological difference might predict the opposite pattern of results than were obtained across the two studies. If participants might have executed eye movements during trials in the present experiment and, as some researchers argue (e.g., Moher & Song, 2014), an eye movement might be considered an action, then one might have expected that would produce equivalent magnitudes of PoP following the two types of trials. However, the present experiment found reduced PoP in absence of motor response whereas Moher and Song found equivalent magnitudes. Future research will be necessary to clarify these issues.

Chapter 4: Experiment 3

4.1 Introduction

The previous experiment isolated the motor response stage of PoP by comparing a condition in which participants viewed the stimuli, located the target and produced a response to a condition in which participants only viewed the stimuli and located the target (but did not make a response). Conversely, Experiment 3 isolated the target localization component of PoP by comparing the typical trial to one in which participants viewed the stimuli and made a response, but did not need to localize the target. On some trials in Experiment 3, participants made an (arbitrary) action as soon as the stimuli appeared. The magnitude of PoP on trials following this task was compared to that following typical trials (where participants additionally localized the target). The results will reveal if arbitrary actions on trial n-1 can produce the typical magnitude of PoP (i.e., whether an action is sufficient to yield PoP). Alternatively, if allocating attention to the target is an essential component in PoP (as suggested by e.g., Kristjansson et al., 2013) PoP might be smaller following an arbitrary action when target localization is not necessary.

4.2 Method

4.2.1 Participants

Twenty undergraduates with normal or corrected-to-normal vision and color vision participated.

4.2.2. Stimuli, Procedure, Apparatus, and Design

The method was the same as in Experiment 1 unless otherwise noted (see Figure 10 for a depiction of method). At the beginning of each trial, participants saw either the word “ACT” or

“NOTCH” above the fixation cross. Participants were instructed that if they saw the word NOTCH when the search array appeared they were to perform the typical PoP task (find the uniquely colored shape and indicate the side of its notch). If they saw the word ACT participants were told to press the space bar as quickly as possible when the shapes (search array) appeared with no requirement to evaluate the search array. On act trials the display terminated upon response (or after 800 ms if participants failed to make a response).

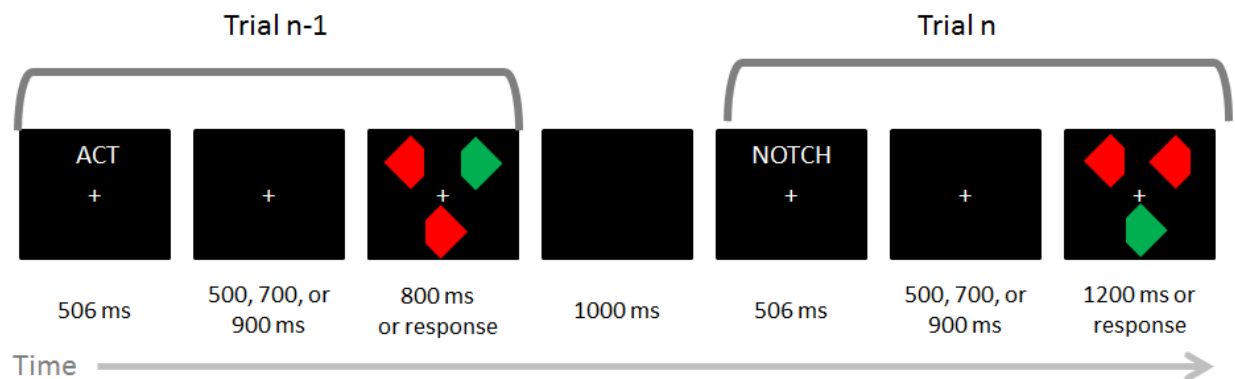


Figure 10. Series of example trials from Experiment 3. A typical trial is preceded by an atypical trial and the target color repeats.

Participants completed a practice block of 24 trials followed by 12 test blocks each containing 60 trials. The 12 unique trials (2 task x 2 target color x 3 fixation duration) in this experiment were repeated five times in each block.

4.3 Results

Response times from the typical trials (with data inclusion criteria as in Experiment 1) were submitted to a 2 (prior task: typical or act) x 2 target color (repeated or switched) repeated-measures ANOVA. The results can be seen in Figure 11. The analysis revealed a main effect of both factors. Participants were faster to respond on typical trials that were preceded by an act trial (631 ms) than preceded by another typical trial (648 ms), $F(1,19) = 34.91, p < .001, \eta^2_p =$

.65. Additionally, as in Experiments 1 and 2, participants were faster to respond on color repeat trials (624 ms) than color switch trials (654 ms; revealing an overall PoP effect of 30 ms), $F(1,19) = 66.75, p < .001, \eta^2_p = .78$. In addition, the two factors interacted, $F(1,19) = 25.66, p < .001, \eta^2_p = .58$, indicating that the magnitude of PoP differed following acting towards the display compared to following a typical task. Although there was reliable PoP following both act trials, $t(19) = 3.60, p = .002$, and typical trials, $t(19) = 7.51, p < .001$, PoP was smaller following an act trial (12 ms) than following a typical trial (48 ms).

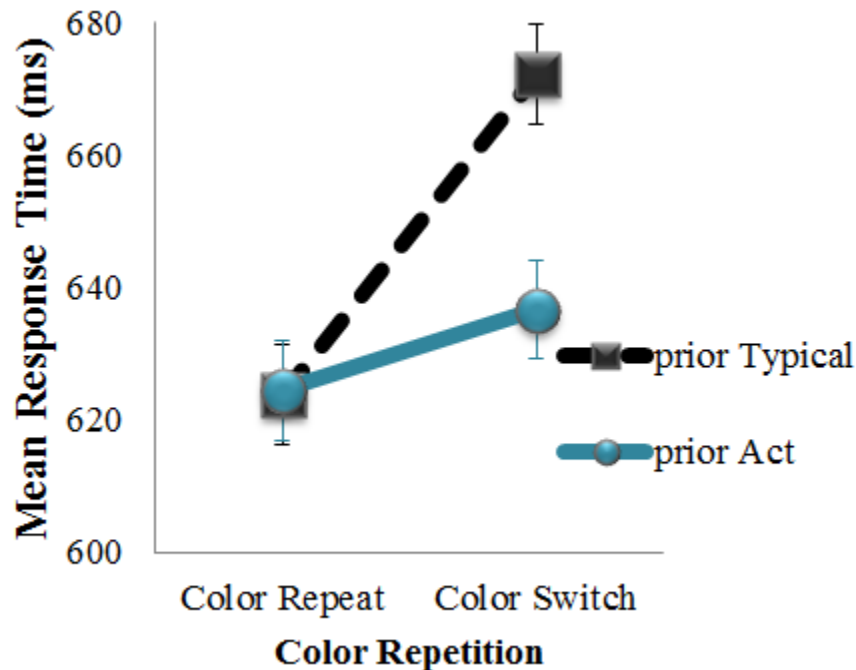


Figure 11. RT data from Experiment 3 as a function of prior trial and color repetition. PoP was reliable following an act trial, although reduced in magnitude compared to when following a typical trial. Error bars represent 95% within subjects confidence intervals

The same 2x2 analysis on accuracy revealed only a main effect of target color, $F(1,19) = 4.57, p = .046, \eta^2_p = .19$, with better performance on color repeat (95.6%) than color switch (94.5%) trials. There was no effect of prior task, nor did the factors interact ($F_s < 1$; see Table 4 for accuracy data by condition).

Table 4

Accuracy (percent correct) in Experiment 3 (SE in parentheses)

Prior Task	Color Repetition	Accuracy (SE)
Typical	Repeat	95.93 (.80)
	Switch	94.52 (.77)
Act	Repeat	95.32 (.89)
	Switch	94.56 (.71)

In addition, for thoroughness, the RT data from act trials were analyzed as a function of prior task and target color. The 2x2 repeated measures ANOVA revealed no main effects or interactions (all $F_s < 1$; see Table 5 for RT data from the action task).

Table 5

Accuracy (percent correct) in Experiment 3 (SE in parentheses)

Prior Task	Color Repetition	RT (SE)
Typical	Repeat	277 (10)
	Switch	278 (10)
Act	Repeat	281 (11)
	Switch	277 (11)

4.4 Discussion

The goal of Experiment 3 was to isolate the target localization component while examining the magnitude of PoP after making an arbitrary response to the stimuli. In this experiment, on some trials participants performed the typical PoP task whereas on some trials participants just viewed the stimuli and made an arbitrary action (i.e., pressed the space bar) as soon as the stimuli appeared. There was reliable PoP following both types of trials, however PoP was reduced following trials in which participants made an arbitrary action (i.e., when the target localization stage was missing).

The reduction of priming following trials in which participants did not need to locate the target fits with recent research emphasizing the importance of target selection in PoP. For

example, Brascamp et al. (2011) intermixed *choice* trials in which participants could freely choose which color item to respond about with typical PoP trials. The researchers found that the target color in the previous typical trial affected which color item was selected in the choice trials, and argued that their data support the importance of attentional selection in PoP. In addition, Kristjansson et al. (2013) used their findings of the absence of PoP following viewing trials to further argue that PoP is “critically dependent upon identifying the target” (p. 517). While the results of Experiment 3 support the idea that selecting the target is an important component in the effect that is typically considered PoP, the present data do not support the stronger claim of Kristjansson et al. that PoP depends critically on target identification. Contrary to this, in the present experiment (and Experiment 1) I found reliable PoP following trials that did *not* require any attentional choice of the target. Therefore, as will be discussed further in the General Discussion, these results imply that attentional choice is not *necessary* to obtain PoP.

A second question the present experiment aimed to address is if, given recent findings about the influence of arbitrary actions on subsequent visual search (e.g., Weidler & Abrams, 2014), an arbitrary action may be sufficient to create the typical magnitude of PoP. The present data do not support this idea; PoP was reduced following an arbitrary action compared to following a typical trial. On the surface this may seem perplexing given that previous research on the action effect has found an arbitrary action does speed times to find a color-matching target on subsequent trials during pop-out search (Weidler & Abrams, 2017). However, as discussed further in the general discussion, there are two important differences between the present paradigm and that typically used in action effect research that may explain this result. Future research will be necessary to disentangle the effects of arbitrary action towards single versus multiple stimuli.

Chapter 5: Between Experiment Analyses

This section reports between-experiment analyses across the three reported experiments.

Figure 12 shows an overview and comparison of the method of all three experiments.

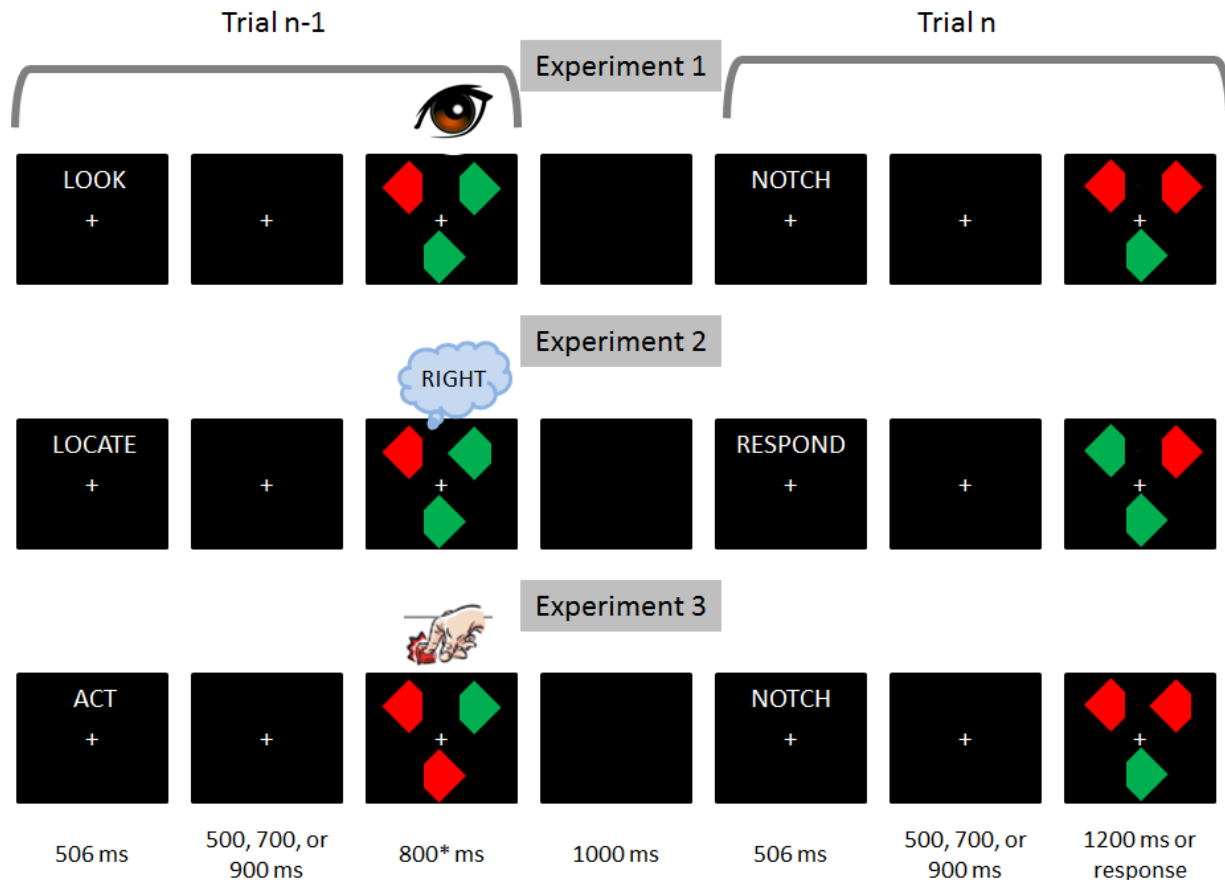


Figure 12. Overview of the method across all experiments. All of these trial sequences represent the case in which a typical trial (Trial n) is preceded by the atypical trial of interest (Trial n-1). Specifically, in the atypical trial of Experiment 1, participants viewed the display until it disappeared; in Experiment 2 participants located the notch in the target and remembered the side until the next trial; and in Experiment 3 participants pressed a key as soon as the display appeared. *In Experiment 3 the display remained on for 800 ms or until response on Act trials. Experiment 1 shows a color switch trial whereas Experiments 2 and 3 show color repeat trials,

For these comparisons, only the parts of Experiment 1 that were comparable to

Experiments 2 and 3 were included: specifically, data only from participants who viewed a three-

item display size and data only from the look/typical phase of the experiment. I first examined if “typical” PoP differed across experiments by performing a 3 experiment x 2 target color repetition (repeat or switch) mixed ANOVA on RT from typical trials that were preceded by typical trials. The analysis revealed only a reliable main effect of color (i.e., the PoP effect) with faster target repetition trials than target switch trials, $F(1,57) = 226.81, p < .001, \eta^2_p = .80$ (see left side of Figure 13, please note that the bars depict the magnitude of PoP, or RT speeding on target color repeat compared to target color switch trials). There was no effect of experiment, $F < 1$, nor did the factors interact, $F(2,57) = 1.08, p = .345$. This implies that across experiments a) the overall average response times were comparable and b) the magnitude of PoP in typical – typical trial sequences was also the same.

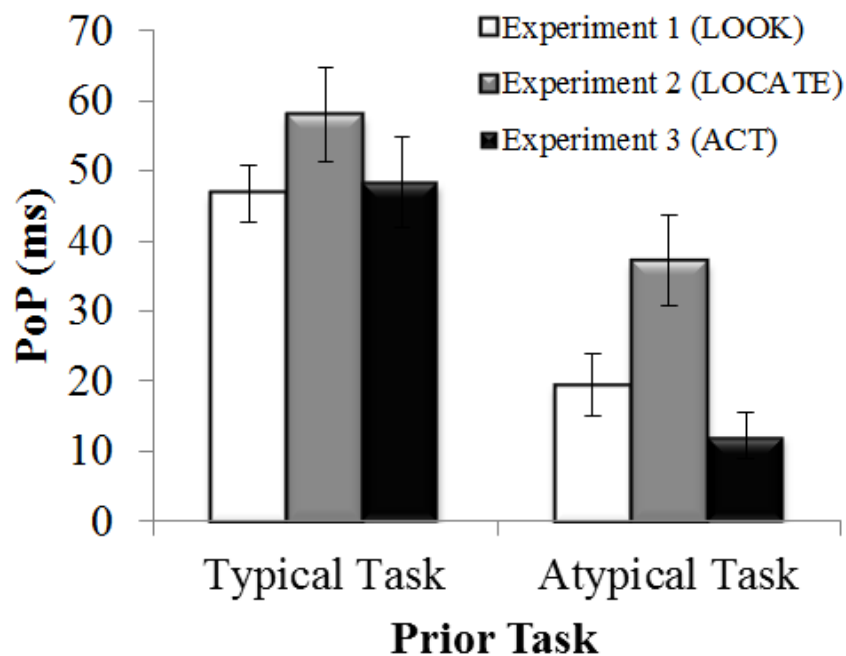


Figure 13. Magnitude of PoP (switch color RT – repeat color RT) as a function of task type (the typical or atypical task) and experiment. A reminder of the atypical task in each experiment is provided in the key. While traditional PoP did not differ across experiments, the magnitude of PoP following the atypical task did (see text for more details). Error bars represent standard errors of the mean.

Confirming the equivalence of overall RTs and PoP effects across experiments allows interpretation of the more interesting analysis that examines how the magnitude of PoP in typical trials that were preceded by *atypical* trials differs across experiments. The same 3 experiment x 2 target color analysis on RTs from typical trials that were preceded by an atypical trial (LOOK trials in Experiment 2, LOCATE trials in Experiment 2, and ACT trials in Experiment 3) again revealed a main effect of target color, $F(1,57) = 64.32, p < .001, \eta^2_p = .53$, and no main effect of experiment $F < 1$. However, in this analysis the factors interacted, $F(2,57) = 6.69, p = .002, \eta^2_p = .19$, implying that the magnitude of PoP following atypical trials differed across experiments (see Figure 13). In order to examine which tasks produced different amounts of PoP, I performed three follow-up 2 experiment x 2 target color mixed ANOVAs. The analysis comparing performing following viewing the stimuli (Experiment 1) compared to viewing the stimuli and locating the target (Experiment 2) revealed an interaction between the factors, $F(1,38) = 5.00, p = .031, \eta^2_p = .12$, because PoP was larger following both viewing and localizing in Experiment 2 (37ms) than just viewing the stimuli in Experiment 1 (20 ms). The same analysis comparing performance following viewing the stimuli (Experiment 1) compared to viewing the stimuli and making an action (Experiment 3) did not reveal an interaction between the factors, $F(1,38) = 1.67, p = .203$, implying that action did not enhance PoP relative to viewing the stimuli alone. Finally, the same analysis comparing performance following trials involving viewing the stimuli and locating the target (Experiment 2) to trials involving viewing the stimuli and making an action (Experiment 3) revealed an interaction between the factors, $F(1,38) = 11.62, p = .002, \eta^2_p = .23$, because PoP was larger in Experiment 2 (37 ms) than Experiment 3 (12 ms). The implications of these data are discussed in the General Discussion.

Chapter 6: General Discussion

To survive in our ancestral past, as well as to navigate present life, efficient visual search of a cluttered environment to identify desired items amongst irrelevant ones is crucial. The phenomenon of PoP that was demonstrated repeatedly in this dissertation illustrates that human vision harnesses a brief memory system that allows previously important features (i.e., the color of a previous target) to affect vision. Such a mechanism might have facilitated picking an additional edible berry among non-edible ones after a previous similar successful foraging outing. However, what in particular about that previous experience facilitates subsequent successful search? Is it viewing the ripe berry among other non-ripe ones, is it visually selecting the berry, or is it reaching out to grab the berry? The present dissertation investigated an empirical analogue of this question – which parts of the typical PoP paradigm are necessary or sufficient to obtain the effect? The general discussion about this work is presented in four sections: a summary of the key findings, implications for theories of PoP, implications for theories about action and perception, and future directions for research in this area.

6.1 Summary of Key findings

The goal of this dissertation broadly was to explore how action, and the other components of PoP, affect that phenomenon. A typical PoP task contains multiple components: (1) viewing the stimulus display, (2) locating the uniquely colored target in the stimulus display, and (3) making the appropriate motor response. Experiments 2 and 3 each removed a single stage from the PoP paradigm in order to isolate that stage's effects on PoP. Specifically, in Experiment 2 the atypical task omitted the motor response stage: Participants viewed the stimuli and located the target and its critical response feature, but did not make a response. On the contrary, in

Experiment 3 the atypical task omitted the stage of locating the target: Participants viewed the display and made a motor response without any other requirements to examine the display.

Experiment 1 compared an atypical task that omitted two of the “stages” of PoP to the typical task--in that task participants only viewed the stimuli, without any requirement to locate the target or make a motor response. That experiment additionally employed a display size manipulation to investigate whether a display size difference in prior research might have contributed to some previously discrepant findings.

Overall, as detailed below, there are three broad conclusions that can be drawn from the present research. First, very little seems necessary to obtain PoP. Second however, each component of PoP seems to contribute a unique role to the overall phenomenon. Third, the display size may affect the magnitude of PoP following passive viewing of the stimuli.

6.1.1. Little is necessary to Produce PoP

One conclusion that can be drawn from the present research is that PoP is a very robust phenomenon. First, in terms of traditional PoP (i.e., when traditional trials were preceded by traditional trials), there was robust PoP across all experiments. In addition, 79 out of the 80 participants run across the three experiments showed positive (i.e., > 0) traditional PoP effects. What is more theoretically interesting though, is that reliable PoP occurred after each of the atypical conditions in every experiment: after trials with no motor component in Experiment 2, after trials with no target localization component in Experiment 3, and after trials lacking both of those stages (i.e., only having passive viewing) in both display sizes three and six in Experiment 1. Taken together, these results imply that very little is *necessary* to produce color-based PoP effects.

6.1.2. Each Component of PoP plays a unique role

However, while the present research has shown that little is necessary to produce PoP, it additionally revealed that each stage in the PoP paradigm plays a measurable role in what is typically considered a measure of PoP. More specifically, across all experiments, the magnitude of PoP was reliably reduced following the atypical task (that was missing at least one component of the typical task) compared to following the typical task. First, in Experiment 1, PoP was reduced following only viewing of the stimuli in both display sizes compared to when all three components of PoP occurred (differences between the display sizes are discussed in the next section). Second, in Experiment 2, PoP was reduced following a task in which participants did not execute a motor response compared to a task which included the motor response in addition to viewing the stimuli and locating the target. Finally in Experiment 3, PoP was reduced following a task in which participants did not locate the target compared to a task that necessitated locating the target as well as viewing the stimuli and executing a motor response. Thus, overall this research reveals that while PoP can occur under conditions as limited as passively viewing a stimulus array, each of the phases in the PoP task as typically studied seem to contribute a unique component to the magnitude of the typical effect.

In addition, between-experiment comparisons imply that certain components of the PoP paradigm may play a larger role than others. Recall that both Experiments 2 and 3 added one additional stage beyond passive viewing. However, while the addition of the target localization stage in Experiment 2 enhanced the magnitude of PoP compared to passive viewing (i.e., there was reliably more PoP following atypical trials in Experiment 2 than Experiment 1), the addition of the motor response stage in Experiment 3 did not increase the magnitude of PoP beyond passive viewing (i.e., there was equivalent PoP following the atypical trials in Experiments 1 and

3; this specific pattern will be discussed further later). A similar conclusion was reached by directly comparing PoP following atypical trials in Experiments 2 and 3; PoP was reliably larger following atypical trials that omitted only the motor component than trials that omitted only the localization component. Taken together, these results imply that locating the target in the search array may play a larger role in PoP than making a motor response. However, more research directly comparing these two stages should be conducted prior to drawing any strong conclusions.

Furthermore, before making a firm conclusion about the importance of each component to obtaining the typical magnitude of PoP, it is worth noting an alternative factor that may have contributed to these results. Specifically, the conclusions of reduced PoP following omission of any of its components from the present research (and that from prior similar research; e.g., Kristjansson et al., 2013; Yashar et al., 2013) inherently rest on comparing trials that could be construed as “task repeat” trials to those which could be construed as “task switch” trials. That is, I compared the magnitude of PoP on a typical task preceded by the same typical task (i.e., when on both trials participants looked for the uniquely colored shape and indicated by key press the side of its notch) to the magnitude of PoP on typical trial preceded by a *different* task (e.g., in Experiment 2 when participants had to search for and remember the location of a notch and then on the next trial look for and respond about the location of that notch). Therefore, perhaps the reduced magnitude of PoP observed following atypical trials across experiments is not because of the cognitive processes involved on the previous trial per se and instead is the result of the task changing between trials (cf. e.g., Monsell, 2003). However, another aspect of the present paradigm--that color was the feature that defined the singleton target--makes this alternative explanation seem unlikely. Thompson and Milliken (2011) asked participants to switch between

either identifying a letter (i.e., T or L) or the tilt of a line (i.e., vertical or horizontal) present in a feature singleton in search arrays. Whereas the authors found a reduction in PoP following task switch trials when the singleton target was defined along certain dimensions (i.e., shape), when the target was a color singleton PoP was equivalent in task switch and task repeat trials.

Therefore, while it cannot be unequivocally ruled out that a change in task played a role in the present results, that possibility seems unlikely given that targets in the present experiments were defined along the dimension of color.

6. 1.3. Display size may influence PoP following passive viewing

A final main implication of the present research stems from the results of the display size manipulation in Experiment 1. Recall that two sets of researchers investigated if PoP occurs following passive viewing of the stimuli. The group who found reliable PoP following passive viewing (Yashar et al., 2013) had a larger number of items in their search displays than the group who found no PoP following passive viewing (Kristjansson et al., 2013). In the present work, half of the participants saw six diamonds in each search trial of Experiment 1, whereas the other half saw three. This manipulation was included because of past work implying more attention may be drawn to a feature singleton (e.g., a single red shape) when there are a greater number of homogenous distractors (e.g., more green shapes; e.g., Bravo & Nakayama, 1992). In the present experiments there was reliable PoP after participants viewed a color singleton amongst two like-colored distractors as well amongst five. However PoP after viewing was marginally reliably greater following when the display contained six elements compared to when it contained three. As discussed earlier, this pattern cannot fully account for the lack of priming following viewing in Kristjansson et al. (2013). However, these data do add a novel contribution to knowledge

about PoP following passive viewing by implying that display size is a factor that modulates the magnitude of PoP in this scenario.

6.2 Implications for theories of PoP

There have been a variety of accounts proposed for PoP over the past 20+ years of research on the phenomenon. Most recent researchers (e.g., Kristjansson, 2016) divide these theories into two broad categories – that PoP affects the time it takes attention to shift to the singleton target and that PoP affects processes after the singleton target has been selected. In addition, a recent account has begun to broadly consider the role of action in PoP. I divide this section into two subsections – the first addressing accounts of traditional priming and the second addressing accounts that consider action. At the end of each of those subsections I discuss the implications of the present results for those accounts.

6.2.1. Traditional Theories of PoP

One account of PoP is that it is results from speeded attentional shifts to the target singleton item when it repeats that of the previous trial. Maljkovic and Nakayama (1994, 1996) argued that on each trial a memory trace is laid down for features of the target (e.g., a trace for red in the case of color PoP). Then, on every new trial, multiple features in the search array compete for attention and those previously strengthened may fare better in that competition. Thus, when the current target shares a feature with one that was enhanced on the prior trial, attention is allocated to that target more quickly and RTs are faster. In support of the idea that priming facilitates the processes prior to target selection, when Goolsby and Suzuki (2001) presented a 100% valid pre-cue at the target's location shortly before the search array's appearance, the magnitude of priming was dramatically reduced. The authors argued that such a virtual elimination of priming when the target's location is known supports the idea that the

primary locus of priming is facilitation of attention being drawn to the target. Further support for this idea comes from research in which Becker (2008) asked participants to manually indicate the identity of a letter inside a size singleton while recording eye movements. She argued that if priming affects processes before the target is selected, RTs to saccade to the target should be affected; conversely if priming affects a process that occurs after the target has been selected then the length of time the gaze lingers *after* the target has been fixated should be affected. In support of the former possibility pinpointing the locus of priming at the earlier phase of visual search, Becker (2008) found a saccade to the target occurred more quickly when it repeated a feature of the previous trial's target.

In contrast to theories that propose an attentional locus for PoP, other researchers have argued that the mechanism of priming occurs after the singleton target has become the focus of attention. In the most influential research supporting the idea that priming's benefit occurs after target selection, Huang et al. (2004) asked participants to search for the uniquely sized target and indicate its orientation. Although the authors found priming for the target-defining feature of size, the response-defining feature of orientation interacted with repetition of size--when size repeated, RTs were faster if orientation also repeated than if it changed. However, when size changed, the pattern reversed and RTs were faster if orientation also changed.

Huang et al. (2004) argued, given that a feature that was not known prior to target selection (i.e., its orientation) influenced performance, priming takes place after attention has been allocated to a specific object when the observer is deciding whether that object is indeed the target. If multiple features on the current object indicate a "yes" response (e.g., both size and orientation are the same as on the prior trial) responding is quick. However, if one feature indicates "yes" and one "no" (e.g., the orientation of the object repeats but its size is different)

this instantiates a more time consuming checking process to verify that the target is indeed what is being attended. A similar account was proposed earlier by Hillstrom (2000) who found that repetition of the response-defining feature (orientation) interacted with repetition of the target defining feature of color. The pattern mirrored the previously discussed pattern of Huang et al.; when color repeated, responses were further speeded if orientation (i.e., the response) also repeated. However, when the focal feature of color changed between trials, RTs were faster if the response also changed (Hillstrom, 2000).

While the goal of the present dissertation was not to distinguish between these two types of accounts, support for a later-stage account can be assessed from additional analyses presented in Appendix A. Those analyses consider the independent variable of target *shape* repetition (i.e., which notch side was missing) in addition to color repetition (and prior task, when applicable). The later (post target-selection; e.g., Huang et al., 2004) account predicts an interaction between the target defining feature of color and the response defining feature of shape. Evidence for that pattern in the present data exists selectively in the beginning phase of Experiment 1 that only contained typical trials: during those blocks, color PoP was reliably larger when the target shape repeated than when it switched (see Figure A1). It should be noted that the interaction takes on a slightly different form than that originally found by Huang et al. (2004)—when the target defining feature of color in the present work switched, similar to Huang et al. RTs were faster when the shape also switched. However, when the color repeated, RTs in the present experiment were equivalent regardless of shape repetition, whereas Huang et al. found speeded RTs when the response defining feature repeated compared to switched in the comparable situation (i.e., when size repeated).

One possibility as to why evidence for the target shape by target color interaction may have not been found in the other experiments comes from research indicating that the *motor* repetition component may be more critical than the *shape* repetition component if PoP occurs primarily at a later stage. Yashar and Lamy (2011) asked participants to perform the typical PoP task: search for the odd-colored diamond and indicate the side of its notch. However, in order to dissociate the response-defining feature repetition and the motor response repetition the authors mapped two features onto one manual response (i.e., press button A if the notch is on the top or bottom and button B if the notch is on the left or right). To strictly isolate motor repetition effects on priming, the authors excluded from one analysis trials in which the response defining feature repeated. Yashar and Lamy (2011) found that in this case response repetition interacted with the focal feature of color (as in e.g., Huang et al., 2004). However, excluding trials when the motor response repeated to isolate the effect of *feature* repetition, response feature repetition did not interact with color repetition. Thus, the authors argued that the locus of post-selection priming is primarily at the motor execution stage and is not as dramatically affected by repetition of the *feature* that alternates or repeats with the response. Therefore, given that in the present research a task requiring no motor response (typical/atypical phase of Experiments 1 and 2) or a different motor response than either of the target shape responses (Experiment 3) was interspersed with typical trials, perhaps support for the late stage account was less likely to occur in the present set of experiments.

Overall, there is some support for a post-target selection account of PoP in the present data: in the typical PoP trials of Experiment 1, repetition of the target shape (and the motor response) interacted with repetition of the target color. However, it should be also noted that there is very clear recent evidence that PoP certainly cannot wholly be accounted for by a post-

selection account. For example, Asgeirsson et al. (2014) argued that they isolated a purely perceptual component of priming. The researchers presented displays containing multiple colored letters very briefly (10-180 ms) and then asked participants to identify the letter in the unique color without any time pressure to respond. Asgeirsson et al. found evidence for PoP beginning with a 20 ms display. Given that the displays were presented very briefly and participants had no time pressure to respond, Asgeirsson et al. (2014) argued that priming can affect processes very early in the search prior to any post-target selection processes being employed. Overall, the current understanding in the literature seems to embrace that PoP can occur at both early attention shifting and late post-target-detection stages (e.g., Kristjánsson & Campana, 2010) and the present data are consistent with that.

6.2.2. Theories of PoP Concerning Action

Recently, some research has begun to consider the role of action in PoP. Specifically, the findings from this dissertation are consistent with Moher and Song's (2014) *action independent* theory of PoP. Moher and Song argued that theoretically, if during a visual search task features of the action made (e.g., a reach or a keypress) are bound critically with features of the target (e.g., red or green) then perhaps feature-based PoP will only occur when the action made repeats as well. To distinguish between this *action dependent* view of PoP and an action independent view, Moher and Song interspersed trials in which participants were asked to reach and point to the uniquely colored diamond with typical PoP trials in which participants indicated the location of the notch on the uniquely colored diamond by keypress. The authors found PoP even when the prior task (i.e., action) differed from the current one, and thus argued that PoP is action independent. The data from all three of the present experiments further support this conclusion. More specifically, if PoP were critically action dependent, then PoP would not be expected

following any of the atypical trials in the present experiments, given that the action executed (none in Experiments 1 and 2, space bar in Experiment 3) differed from that of the typical trial (arrow key press). However, supporting Moher and Song's conclusion that PoP is action independent, PoP was found in these scenarios across all experiments.

6.3 Implications for the role of action in perception

The present findings also have implications for an understanding about the ways in which action can affect perception. One recent finding is that a simple arbitrary action (a key press) towards an object can affect how attention is subsequently allocated to that object's features during visual search. Even when those features are irrelevant to the observers' goals, participants tend to look towards those features first (Weidler, Suh, & Abrams, 2017) and are faster to respond about unrelated targets associated with those features (Buttaccio & Hahn, 2011; Weidler & Abrams 2014, 2017abc). In addition to the recent investigations of the role of motor response in PoP (e.g., Yashar et al., 2013), the *action effect* findings from the action and perception research (e.g., Buttaccio & Hahn, 2011) spurred examination of the role a motor response plays in PoP in the present work. Based on this earlier research--specifically results indicating that an arbitrary action can influence visual search when observers search for a color singleton target (Weidler & Abrams, 2017c)--one might have expected trials including a motor response to result in a magnitude of PoP comparable to that from a typical trial. However, that is not the pattern revealed in the present data. In Experiment 3, PoP was reduced following trials that involved viewing the stimuli and making an arbitrary response (i.e., a manipulation similar to those in action effect experiments) compared to following the typical task. Furthermore, between-

experiment comparisons revealed that viewing the stimuli *and* making an action did not enhance the magnitude of PoP beyond viewing the stimuli alone⁴.

Why did an arbitrary action not enhance the magnitude of PoP beyond viewing in the present research? There are two main reasons why this may be the case that stem from differences between the paradigm in which the effects of arbitrary action have been investigated in the past (i.e., the action effect paradigm) and the current paradigm. Recall that in a typical action effect task there are two parts of each trial – the action task and the search task. The visual search task in some action effect work is conceptually identical to the search task performed on the typical trials in the present research. For example, Weidler and Abrams' (2017c) search arrays contained three circles that each contained a tilted line, one of which had a unique color. Participants' task was to identify the tilt of the line in the uniquely colored circle. Analogously, the search arrays in the present Experiment 3 contained three diamonds, one of which had a unique color, each of which had a notch missing, and participants' task was to identify the notch location on the uniquely colored shape.

However, while the visual search task is very similar across paradigms, the action task in action effect research differs in two potentially important ways from the “ACT” trials in the present Experiment 3. First, during the action effect paradigm participants respond to a *single* colored element whereas in the present research participants made an arbitrary action to multiple

⁴ Two additional follow-up experiments were conducted to ensure that two methodological aspects of Experiment 3 – the reduced time viewing the stimuli in atypical trials in Experiment 3 vs. 1 and the switch between response hands from atypical to typical trials in Experiment 3 (cf. e.g., Hommel, 1998) -- were not contributing to this pattern of unexpectedly small PoP effects following a motor response. Experiment 3B was identical to Experiment 3 except that the display did not terminate upon response during ACT trials (i.e., stimuli remained present for 800 ms) and Experiment 3B was identical to Experiment 3 except that participants only used their right index finger to respond to both tasks; on ACT trials they pressed the up arrow key as soon as the stimuli appeared. More detail can be found in Appendix B, but the results from both of these experiments replicated Experiment 3 almost exactly. PoP was reliably reduced following atypical trials (14 ms in 3B, 15 ms in 3C) compared to typical trials (54 ms in 3B, 60 ms in 3C). Additionally, between experiment comparisons revealed that PoP following atypical trials in both experiments did not differ in magnitude following the atypical LOOK condition in Experiment 1 and was reduced compared to the atypical LOCATE condition in Experiment 2.

colored elements. Researchers have speculated that the action effect arises because an action towards an object signals its “importance” and then its features are subsequently prioritized (e.g., Abrams, Weidler, & Suh, 2015). If that is the case, then perhaps all of the objects (i.e., objects of both colors) were tagged as “important” following an action in the present experiments. However, given that the two colors present during the action comprised both the target and distractor elements on the subsequent trial, this distributed importance signal from action would not be expected to favor the target, and hence it did not enhance the magnitude of PoP. A second potentially important difference is that in the present Experiment 3, a key press action was made on *every* trial whereas in the action effect paradigm, trials in which participants do not respond are interspersed and compared to trials in which participants respond. It may be the case that an action signals “importance” only *relative* to no action.

6.4 Future directions

While the present work began to fully explore the role of action in PoP, there are numerous questions that remain to be examined in future research. A first avenue would be to systematically examine the role of two factors that differ between PoP paradigms compared to the action effect paradigm in the context of visual search. Specifically, future research should investigate the effect of (a) responding to a single versus multi item display and (b) interspersing action with no action trials. A first step towards exploring the role of single versus multi-item displays could be to have participants perform an action effect task where during the action task they respond to multiple items that share the *same* feature. Earlier I speculated that the lack of a boost in PoP from an arbitrary motor response in the present research comes from a distributed effect of action across all elements (that have multiple colors). However, it is an open question if an arbitrary action can potentiate a multiple-item display, as all evidence for the action effect has

come from scenarios in which participants respond to a single item (Buttaccio & Hahn, 2014; Weidler & Abrams, 2014; 2017). Then, a second step to examining the second question could be to conduct an experiment that includes conditions from both the present Experiment 1 and Experiment 3 – more specifically, participants would experience “LOOK”, “ACT”, and “NOTCH” trials in a single experiment. Assuming action can potentiate a multiple-item display, such an experiment would afford an assessment of whether an arbitrary action only modulates subsequent search when compared to scenarios in which no action is made.

In addition, future research should examine how passive viewing of PoP arrays affects subsequent PoP when eye movements are restricted. In the present work (as well the prior investigations that evaluated PoP following passive viewing, Kristjansson et al., 2013; Yashar et al., 2013) while a fixation cross was present prior to the trial and throughout the search displays, participants’ eye movements were not restricted in any way. Given that some researchers have argued that eye movements may be considered actions (e.g., Moher & Song, 2014), in order to more purely assess if PoP can occur following *passive* viewing, future research should examine that question while eye movements are restricted.

Finally, an interesting direction for future research would be to systematically examine how the removal of the phases of the PoP task explored in the present research (i.e., the target localization or the motor response stage) affect both target facilitation and distractor inhibition processes in PoP. Recall, that only two colors were used in the displays of the present experiments. Therefore, the PoP effect in the present experiments included benefits of repeating the target color as well as repeating the distractor color (that was presumably inhibited in trial n-1). However, past research has shown that the PoP benefits of repeating a target color and repeating a distractor color produce separate and dissociable priming effects (e.g., Lamy et al.,

2008). Future research should examine if the removal of various components of the PoP paradigm affect these two components of PoP differentially.

6.5 Conclusions

PoP reveals the intelligence of the human visual system – even in the face of bottom-up stimulus salience and observers’ goals (cf. e.g., Awh et al., 2012), features that were simply previously behaviorally important are prioritized. A main empirical contribution of the present research is the knowledge that what is typically considered PoP (cf. e.g., Kristjansson & Campana, 2010) includes facilitation based on multiple processes involved in the previous visual search task that can be dissociated. Therefore, future research examining how other factors influence PoP should consider which components of PoP are affected by the manipulation.

Additionally, this research offers a preliminary answer regarding which parts of the berry-picking process may predict the success of a future foraging attempt. More specifically, does the benefit arise from viewing a scene that had a unique ripe berry amongst non-ripe ones, from choosing a berry to pick, or from making an action to pick that berry? A first conclusion from this research is that any and all of these components of the experience would aid future success of finding a similar berry– the results of Experiment 1 imply that merely viewing a scene with a uniquely colored berry would facilitate finding a similar one in the future. However, a second conclusion from the present research is that efficient foraging will be most facilitated by a previous experience that additionally involves locating a desired berry and picking it. Behavior will not be facilitated to the same degree if, for example, an individual located a berry but was interrupted before being able to pick it (cf. Experiment 2). Similarly, there would be less future facilitation if while beginning to examine the environment one was forced to swat a fly before locating a ripe berry (cf. Experiment 3). Overall, this research reveals how momentary

interpretation of a visual scene is powerfully influenced by past experience with and actions towards the environment.

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Appendixes

Appendix A: Target Shape/Response repetition analyses

In the present experiments, color was the target-defining feature used to invoke PoP. However, in addition to the target color repeating or switching on each trial, the target's *shape* (i.e., whether the diamond was notched on the left or the right) also repeated or switched on every trial. Note that target shape repetition is perfectly confounded with target response repetition when typical trials are preceded by typical trials. However, I will refer to the variable as *target shape* given that this term is applicable to all trial types in each experiment, including trials following those in which there was no response. This section presents RT analyses of the earlier experiments incorporating this independent variable. I only discuss results concerning main effects or interactions with the shape variable.

Experiment 1

A 2 display size x 2 color repetition x 2 shape repetition mixed ANOVA (with display size as the between subjects factor) was first conducted on the typical only trials of Experiment 1 (i.e., before the atypical task was intermixed). This analysis revealed a main effect of shape, $F(1,38) = 7.47, p = .009, \eta^2_p = .16$, with faster responses when the target shape switched (642 ms) than when it repeated (649 ms; cf e.g., Hillstrom, 2000; Hommel, 1998 for similar patterns in the literature). In addition, color repetition interacted with shape repetition, $F(1,38) = 9.65, p = .004, \eta^2_p = .20$ (see Figure A1). This interaction arose because color PoP was larger when the target shape repeated (56 ms) than when it switched (41 ms). Shape did not interact with display size, $F(1,38) = 2.14, p = .15$, nor was it involved in a three-way interaction, $F < 1$. Follow-up

analyses confirmed that similar to prior work (e.g., Huang et al., 2004), when the target defining feature of color switched, RTs were 14 ms faster when the response defining feature of shape switched compared to when it repeated, $t(39) = 3.90, p < .001$. However, when color repeated, RTs were equivalent for shape repeat and switch trials, $t < 1$.

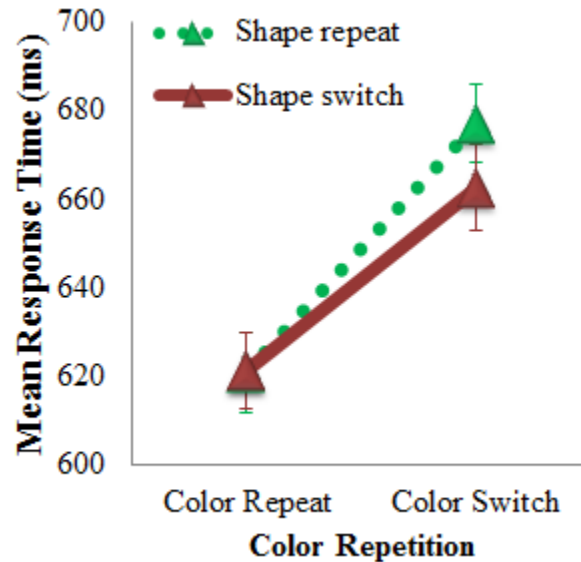


Figure A1. RT as a function of color repetition and shape repetition (collapsed across display sizes) from the typical only phase of Experiment 1. The interaction arose because color PoP was larger when the target shape repeated than when it switched. Error bars depict standard errors of the mean.

A 2 display size x 2 prior task x 2 color repetition x 2 shape repetition display mixed ANOVA (with display size as the single between-subjects factor) on RTs from the phase of Experiment 1 that involved typical and atypical (i.e., LOOK) trials revealed no main effect of shape, $F(1,38) = 1.66, p = .205$, nor was shape involved in any two-way interactions with display-size, prior-task, or color ($F_s < 1$). Neither the three-way interaction between display size, prior task, and shape ($F < 1$) nor the three-way interaction between display size, color, and shape, $F(1,38) = 2.39, p = .131$, were significant. However, there was a reliable four-way interaction between the factors, $F(1,38) = 7.43, p = .010, \eta^2_p = .16$ (see Figure A2; note that the dependent variable is color PoP).

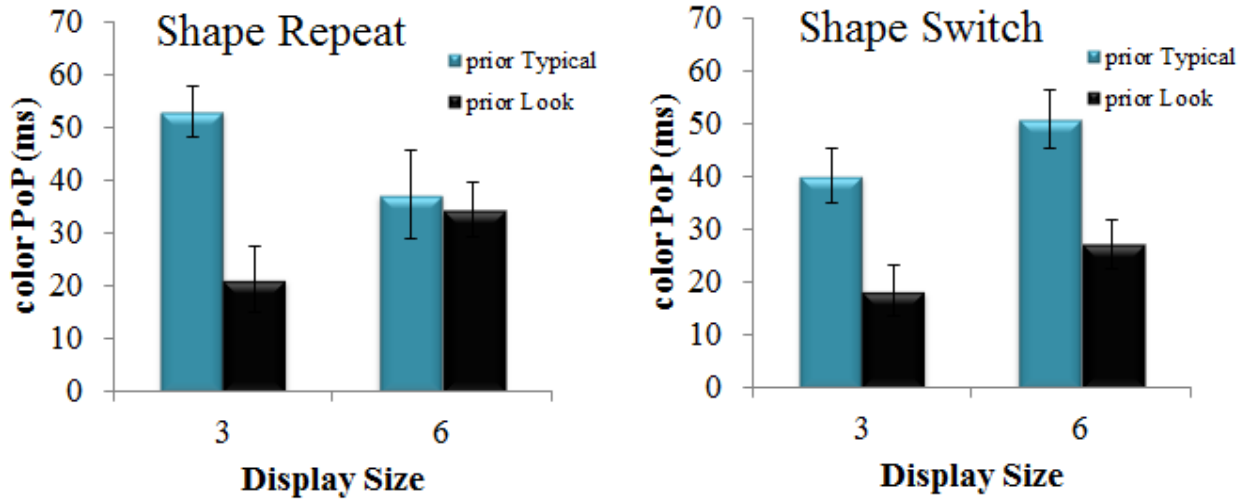


Figure A2. Color PoP effects (color switch – color repeat RT) as a function of target shape, display size, and prior task. The three-way interaction between display size, prior task, and target color was only reliable when the target shape also repeated.

To further decompose this interaction, I examined how the three way interaction of display size, prior task, and target color reported in Experiment 1 was modulated by shape repetition. A 2 display size x 2 prior task x 2 target color mixed ANOVA was first conducted on trials in which the target shape repeated, revealing a reliable three way interaction between the factors, $F(1,19) = 7.35$, $p = .010$, $\eta^2_p = .16$. However, the same analysis on trials in which the target shape switched did not reveal that three-way interaction, $F < 1$. Therefore, the exaggerated difference in PoP following viewing and typical trials in display size three compared to six was only apparent when the target shape repeated.

Another way of framing these results is that there is one scenario in which color PoP is equivalent following viewing the stimuli and performing the typical task – when there are six items in the display and the target shape repeats between trials (see right bars in left panel of Figure A2). Statistics confirm this conclusion: a 2 prior task x 2 target color ANOVA revealed a reliable interaction in display size 3 when the target shape repeated, $F(1,19) = 20.83$, $p < .001$, $\eta^2_p = .52$, or switched, $F(1,19) = 12.34$, $p = .002$, $\eta^2_p = .39$, and in display size 6 when the target

shape switched, $F(1,19) = 16.84, p = .001, \eta^2_p = .47$. However, the interaction was not reliable in display size 6 when the target shape repeated, $F < 1$. Why might this occur? If there were to be a scenario in which PoP in the more “minimal” task (i.e., viewing) is equivalent to that in the typical task, one might expect it to occur in the larger display size when the target shape repeats. Research has shown that pop-out effects (e.g., capture of attention by a unique color amongst like colored distractors) are stronger at larger display sizes (e.g., Bravo & Nakayama, 1992; Weidler & Abrams, 2017c), so it can be assumed that, despite not task-necessitated on the atypical trials, attention may have been captured by the color singleton more strongly in display size 6 than display size 3. Then, assuming attention was drawn to the singleton, color PoP on the subsequent trial should be stronger in the case when the shape of the target repeats. This follows from past research indicating that when shape repeats between two successive visual events, RTs are faster when the color also repeats compared to the color switching (whereas when shape switches between trials that pattern is eliminated or reversed; e.g., Hommel, 1998). Stated another way, a condition in which the color singleton is likely to be attended on trial $n-1$ (i.e., in display size 6) and the shape is repeated between trials is particularly conducive to demonstrating speeding on color repeat compared to color switch trials on trial n (i.e., to observing comparable color PoP in the atypical viewing condition as in the traditional condition).

Experiment 2

A 2 prior task x 2 target color x 2 target shape repeated-measures ANOVA revealed a marginally reliable main effect of shape, $F(1,19) = 3.92, p = .062, \eta^2_p = .17$, with faster responding when the target shape switched (633 ms) than when it repeated (640 ms). Shape did not interact with prior task or color, nor was there a three-way interaction (all F s < 1).

Experiment 3

The same 2x2x2 ANOVA on Experiment 3 RT data similarly revealed a main effect of shape, $F(1,19) = 4.69$, $p = .043$, $\eta^2_p = .20$, with faster responding when the target shape switched (636 ms) than when it repeated (643 ms). In addition, shape marginally interacted with prior task, $F(1,19) = 3.09$, $p = .095$, $\eta^2_p = .14$. This trend towards an interaction arose because there was a greater slowing on shape repeat than shape switch trials following a typical task (13 ms) than following an atypical (i.e. ACT) trial (3 ms). Shape did not interact with color, $F < 1$, nor was the three-way interaction reliable, $F(1,19) = 2.77$, $p = .112$.

Appendix B: Experiments 3B and 3C

In Experiment 3, PoP was substantially reduced following an arbitrary action compared to the typical PoP task. Indeed, the PoP following an arbitrary action in that experiment was numerically smaller than the PoP found in the display size 3 (i.e., the comparable display size) of Experiment 1 when participants just viewed the stimuli and did not respond. Experiments 3B and 3C examined two methodological details that may have accounted for this unexpectedly small amount of PoP. First, because the search display terminated upon response, participants saw the stimuli on average for a briefer time on action trials in Experiment 3 than on typical trials or on the view trials in Experiment 1 (when the display remained on for 800 ms). Second, in Experiment 3 participants pressed the space bar on atypical ACT trials with their left hand but responded on typical trials with their right hand. Previous research has shown that responses to the same features across trials (e.g., responding to a red target followed by a red target, or a color repeat trial in the present experiments) are slowed when the response hand changes (e.g., Hommel, 1998). Therefore, it is possible that switching hands might have contributed to the reduced priming effect following ACT trials in Experiment 3. Experiment 3B equated viewing time between conditions; in Experiment 3C participants used the same finger to respond on all trials.

Method

Participants. Twenty additional undergraduates participated in each experiment.

Stimuli and Procedure. The method in Experiment 3B was identical to Experiment 3 except that on “ACT” trials the search display remained visible for 800 ms regardless of when participants pressed the space bar (i.e., the display did not terminate upon response). The method

in Experiment 3C was identical to that of Experiment 3 except that participants only used one finger (their right index finger) to respond. They were asked to rest it on the down arrow key between each trial, and to respond only with that finger throughout the experiment (compliance with this instruction was monitored with a camera). On ACT trials participants pressed the up arrow key as soon as the display appeared and on typical trials they used the left or right arrow keys to indicate the target's notch location as in Experiment 3.

Results

Experiment 3B. See Figure A3 for the results of a 2 prior task x 2 target color repeated measures ANOVA on RT. The analysis revealed a main effect of prior task, $F(1,19) = 30.54$, $p < .001$, $\eta^2_p = .62$, with faster RTs following atypical act trials (627 ms) than typical trials (644 ms). There was also a main effect of target color, $F(1,19) = 92.24$, $p < .001$, $\eta^2_p = .83$ (i.e., PoP) with faster response to repeated (618 ms) than switched (652 ms) target colors. In addition, as in Experiment 3, the two factors interacted, $F(1,19) = 35.76$, $p < .001$, $\eta^2_p = .65$, because PoP was larger following a typical trial (54 ms) than following an action trial (14 ms; see Figure A3). However, as in Experiment 3, PoP was reliable following an action trial, $t(19) = 3.24$, $p = .004$.

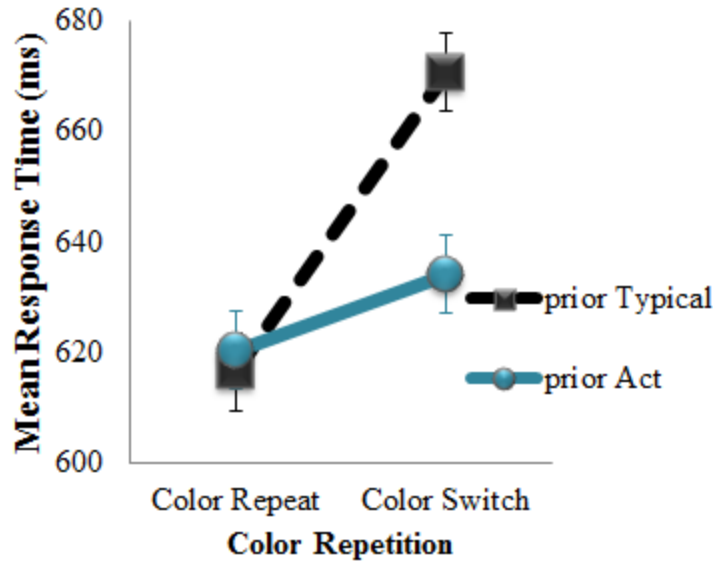


Figure A3. Results of Experiment 3B replicated Experiment 3 almost exactly despite the fact that stimuli were visible on atypical trials longer than in Experiment 3 (and longer than the average typical trial RT). Error bars represent within subjects 95% confidence intervals.

The same analysis on accuracy revealed only a main effect of target color, $F(1,19) = 10.29, p = .005, \eta^2_p = .35$, with better performance on color repeat (97.4% correct) than color switch trials (95.2%).

Table A1

Accuracy (percent correct) in Experiment 3B (SE in parentheses)

Prior Task	Color Repetition	Accuracy (SE)
Typical	Repeat	97.34 (.48)
	Switch	94.62 (.85)
Act	Repeat	97.51 (.54)
	Switch	95.83 (.72)

Experiment 3C. A 2 prior task x 2 target color repeated measures ANOVA on RT revealed a main effect of prior task, $F(1,19) = 59.75, p < .001, \eta^2_p = .76$, with faster RTs following atypical ACT trials (663) than typical trials (684). There was also a main effect of target color, $F(1,19) = 72.45, p < .001, \eta^2_p = .79$ (i.e., PoP) with faster responses to repeated (655) than switched (693) target colors. In addition, as in Experiment 3, the two factors

interacted, $F(1,19) = 54.45, p < .001, \eta^2_p = .74$, because PoP was larger following a typical trial (60 ms) than following an atypical action trial (15 ms; see Figure A4). As in the previous experiments however, PoP was still reliable following atypical trials, $t(19) = 3.37, p < .001$.

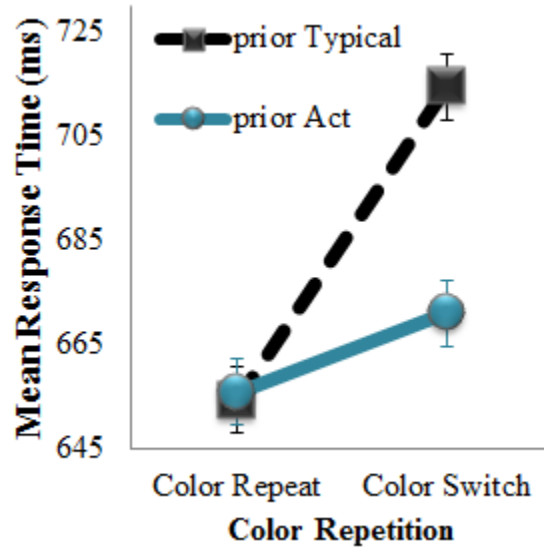


Figure A4. Results of Experiment 3C replicated Experiment 3 almost exactly despite the fact that participants responded with the same finger on all trials. Error bars represent within subjects 95% confidence intervals.

The same analysis on accuracy revealed a main effect of prior task, $F(1,19) = 14.61, p = .001, \eta^2_p = .44$, with better performance following atypical (96.7% correct) than typical (95.0%) trials. Additionally, there was a main effect of target color, $F(1,19) = 6.25, p = .022, \eta^2_p = .25$, with better accuracy when the color repeated (95.2%) than when it switched (96.5%). The two factors did not interact, $F(1,19) = 2.07, p = .166$.

Table A2

Accuracy (percent correct) in Experiment 3C (SE in parentheses)

Prior Task	Color Repetition	Accuracy (SE)
Typical	Repeat	96.10 (.79)
	Switch	93.93 (1.11)
Act	Repeat	96.97 (.80)
	Switch	96.44 (.51)

Between Experiment Comparisons. For thoroughness, the magnitude of PoP following atypical ACT trials in Experiments 3B and 3C was compared to the magnitude of PoP following atypical LOOK trials in display size 3 of Experiment 1 as well as to the atypical LOCATE task trials in Experiment 2. As with Experiment 3, PoP following ACT trials was equivalent to PoP following LOOK trials in Experiment 1 in both Experiment 3B, $F < 1$, and Experiment 3C, $F < 1$. Additionally, as with Experiment 3, PoP was reliably reduced following ACT trials compared to following atypical LOCATE trials in Experiment 2 in both Experiment 3B, $F(1,38) = 9.09$, $p = .005$, $\eta^2_p = .19$, and Experiment 3C, $F(1,38) = 8.93$, $p = .005$, $\eta^2_p = .19$.

Discussion

The results of Experiment 3B and 3C imply that neither reduced exposure duration to the stimuli nor a hand switch selectively following act trials can account for the small magnitude of PoP following act trials in Experiment 3. Thus, by ruling out alternative explanations for the findings of Experiment 3, these findings permit a stronger conclusion about the motor response stage's role relative to other components of the PoP paradigm.