THREE PERCEPTUAL EFFECTS PRODUCED WITH COLOR IMAGERY

IMAGERY IS LIKE PERCEPTION: THREE PERCEPTUAL EFFECTS PRODUCED WITH COLOR IMAGERY

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Lay Abstract

It is not well understood the degree to which the contents of our ‘mind’s eye’ can interface with the perceptual world. We explored this topic using color imagery and evaluated whether these representations could influence how we process perceptual objects. First, we found that visual imagery can help locate matching objects when they need to be found amongst distracting objects. Second, we found that visual imagery during actions could be formed into memory representations that influence our ability to discriminate objects. Lastly, we found that visual imagery, though it often facilitated the identification of matching objects, it can sometimes make matching objects harder to identify. These findings demonstrate that visual imagery can have a very real influence on our interactions in the perceptual world.

Abstract

Investigations of visual imagery are as old as documented scientific inquiry. Despite this, there is still little understanding of how visual imagery interfaces with our perceptual world. In the present thesis, I investigated three perceptual effects to evaluate whether they were influenced by color imagery. The first effect is an inter-trial priming effect known as the Priming of Pop-out (PoP) effect that constitutes faster responding when the target and distractor colors are repeated than when they are switched across trials of visual search. Here, it was demonstrated that when color imagery was put in opposition with the color of previous target, a pattern of results emerged that was opposite that of the PoP effect – suggesting that color imagery interacted with the representations typically driving the PoP effect. The second effect were those associated with stimulus-response (S-R) bindings, often termed event file binding effects. In a typical event file procedure, it is demonstrated that performance is efficient when an arbitrary key-press is made in response to color stimuli that either completely match or mismatch the S-R bindings of a following two-alternative force choice (2AFC) task, and inefficient when there is partial overlap between these S-R bindings. We demonstrated that color imagery bound to arbitrary responses could produce quite similar effects on a 2AFC color discrimination task as those produced by perceptual colored stimuli. The last effects were the facilitation and inhibition effects observed across trials of 2AFC tasks when targets are presented in the same location. Here it was demonstrated that both perceptual and imagined colored targets led to fast responding when they matched perceptual color targets on the following trial than when they mismatched. When an irrelevant task intervened between these targets, the opposite pattern of results was observed; responses were slower when either the imagined or perceptual targets matched than when they mismatched. This suggests that color imagery could produce priming or habituation-like effects much like perceptual colors. Overall, the present thesis supports the idea that color imagery can influence many of the processes guiding our behavior in the perceptual world.

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Preface

This is a ‘sandwich’ thesis, meaning that each empirical chapter (i.e., Chapters 2 to 5) was written as a standalone research article. Chapters 2, 3, and 4 are published in peer-reviewed journals. Chapter 5 is under review at a peer-reviewed journal. I am the first author on these articles, and my supervisor, Bruce Milliken, is final author. My contribution to each manuscript is outlined below.

The first empirical chapter (Chapter 2) is a reprint of Cochrane, B. A., Nwabuike, A. A., Thomson, D. R., & Milliken, B. (2018). An imagery-induced reversal of intertrial priming effects in visual search. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 4*(44), 572-587. My role in the manuscript included writing, experimental design, programming, statistical analyses, and data collection.

The second empirical chapter (Chapter 3) is a reprint of Cochrane, B. A., Siddhpuria, S., & Milliken, B. (2019). Cueing color imagery: a critical analysis of imagery-perception congruency effects. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 45*(8), 1410-1421. My role in the manuscript included writing, experimental design, programming, and statistical analyses.

The third empirical chapter (Chapter 4) is a reprint of Cochrane, B. A., & Milliken, B. (2019). Imagined event files: an interplay between imagined and perceived objects. *Psychonomic, Bulletin, & Review, 26*(2), 538-544. My role in the manuscript included writing, experimental design, programming, and statistical analyses.

The fourth empirical chapter (Chapter 5) is a manuscript entitled ‘the representational basis of non-spatial facilitation and inhibition effects’ by Brett A. Cochrane and Bruce Milliken is under review at the *Journal of Experimental Psychology: Human Perception and*

Performance. My role in the manuscript included writing, experimental design, programming, and statistical analyses.

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Figure 7. An example of a trial pair sequence for the imagine-new condition of Experiment 3. In the imagine-opposite condition of Experiment 3, participants performed the task shown in Figure 2, but also rated their imagery following each pair of trials as shown in this figure.

Figure 8. Mean response times (ms) for congruent and incongruent trials in the imagine-new and imagine-opposite conditions in Experiment 3. Error bars represent standard errors of the means corrected to remove between-subject variability (Cousineau, 2005; Morey, 2008).

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Figure 1. This figure depicts a typical trial sequence across experiments. Across all experiments the trial sequence was identical with the exception of the target display. In Experiment 1, participants were required to identify one of six colors by selecting the corresponding key. In Experiment 2, participants performed the same task except that there were only two possible colors. In Experiment 3, participants indicated the side of the gap of the colored square. In Experiments 4a and 4b, participants indicated the side of the gap of the colored square when the target's location was uncertain. In Experiments 5a and 5b, participants

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Chapter 1: Introduction

Visual imagery is a perception-like experience that occurs in the absence of appropriate external stimuli. Visual imagery is thought to play an important role in many cognitive processes such as those associated with memory (Hatakeyama, 1998; Paivio, 1986), motivation (McMahon, 1973), visuo-spatial reasoning (Kosslyn, Ball, and Reiser, 1978; Shepard & Feng; 1972; Shepard & Metzler, 1971) and creativity (Miller 2000; Shepard & Cooper, 1982). It is debated in cognitive psychology whether imagined representations are phenomenologically similar to those produced by external stimuli (Tye, 1991). An empirical approach for assessing this issue has been to compare behavioral performance across tasks that have used imagery in place of external stimuli. If behavioral performance across imagery and perception tasks is identical, it may be concluded that the same underlying processes support imagery and perception. This thesis describes a close investigation of this issue – that is, I evaluate whether specific cognitive effects can be produced when visual imagery is used in place of the relevant external stimuli. The three primary effects evaluated are: (i) the Priming of Pop-out effect, an intertrial priming effect observed in singleton search tasks (Chapter 1 and 2); stimulus-response binding effects observed in stimulus discrimination tasks (Chapter 3); and intervening event modulated inhibition effects observed in target-to-target discrimination tasks (Chapter 4). Understanding when imagery does and does not produce results akin to external stimuli can offer insight into the underlying processes guiding these effects (see the General Discussion for details).

A brief history of visual imagery

One of the first scientific studies exploring visual imagery was conducted by Galton (1880; 1883). Participants were required to recall specific everyday scenes (e.g., the appearance of their breakfast table), then report the vividness of their visual imagery of these scenes (e.g., 'brilliant, distinct, never blotchy'). Galton observed that participants from 'general society' appeared to have more vivid visual imagery compared to scientists, concluding that scientists have poor visual imagery ability. Later work has questioned the scientific merit of Galton's findings (Brewer & Achommer-Aikins, 2006). Brewer and Achommer-Aikins examined Galton's published data and found that Galton's conclusions were not supported. Further, they replicated Galton's study and observed that scientists did not have less vivid visual imagery abilities compared to a non-scientist group of participants. Nonetheless, Galton's study offers an important first investigation into visual imagery.

In the following era, research on visual imagery did not progress much. This lack of progress was due to the rise of behaviorism, which was theoretically opposed to notions of introspection. One of the leading psychologists of the time, James B. Watson, believed that thinking was simply talking to oneself and it was accompanied by undetectable throat twitches (Watson, 1913). With respect to visual imagery Watson (1928, p. 76-77) writes:

> What does a person mean when he closes his eyes or ears and says, 'I see the house where I was born, the trundle bed in my mother's room where I used to sleep – I can even see my mother as she comes to tuck me in and I can even hear her voice as she softly says good night?' Touching, of course, but sheer bunk. We are merely dramatizing. The behaviorist finds no proof of imagery in all this. We have put all these things in words, long, long ago.

Another behaviorist, B. F. Skinner, had a different approach to addressing visual imagery. Though he believed that visual imagery existed in a phenomenological sense, he did not believe there was any utility in studying it. Skinner (1974, p. 82-84) writes:

> Behaviorism has been accused of ‘relegating one of the paramount concerns of the earlier psychologists – the study of the imagery – to a position of not just neglect, but disgrace.’ I believe, on the contrary, that it offers the only way in which the subjects of imaging or imagining can be put in good order … Seeing the absence of the thing seen is familiar to almost everyone, but the traditional formulation is a metaphor. We tend to act to produce stimuli which are reinforcing when seen … A person is changed by the contingencies of reinforcement under which he behaves; he does not store the contingencies. In particular, he does not store copies of the stimuli which have played a part in the contingencies. There are no ‘iconic representations’ in his mind; there are no ‘data structures stored in his memory’; he has no ‘cognitive map’ of the world in which he lives. He has simply been changed in such a way that stimuli now control particular kinds of perceptual behavior.

It should be noted however, that Skinner’s views on visual imagery appear to be contradictory; at times, he maintained a strong behaviorist stance on visual imagery, at other times, he held that visual imagery (e.g., in the form of visualization of actions) could act to reinforce external behaviors (Skinner, 1953; 1974).

In the following years, there was renewed interest in imagery coinciding with what has been termed the cognitive revolution. The cognitive revolution marked the period when the predominance of behaviorism in psychology ended, and an emphasis was placed on mental processes as the central focus of psychology (Baar, 1986; Gardner, 1987). This renewed interest in mental processes coincided with several key research developments at the time. One particularly important investigation was that conducted by Miller (1956; see also Hick, 1952). In summary, Miller had participants memorize a list of tones and had them recall these tones while varying a number of different task parameters. Miller's findings revealed that memory recall depended on the relationship between list items, demonstrating a phenomenon known as chunking. Arguably more important than this finding itself, Miller demonstrated an empirically measurable way to investigate mental processes that revitalized scientific interest on the topic.

Another historically important study was that of Sternberg (1969a), who described procedures for identifying mental processes using response time measures. Sternberg based his research on the work of Donders (1969; originally authored in 1868), who proposed that every mental process takes an amount of time, and that by adding and subtracting components of a cognitive task one is also adding and subtracting mental processes – termed pure insertion. Based on the rationale of pure insertion, the time to complete a two alternative forced choice discrimination task should be the sum of the time to simply respond to a stimulus and the time required for any process or processes involved in the discrimination aspects of the task. Sternberg extrapolated on the ideas of Donders, proposing the additive-factor method – that independent components of a task can reveal how different processes interact. If one factor affects response time independent of another factor, then it is concluded that these two factors affect different processing stages. However, if two or more factors interact, then it is presumed that these factors influence the same processing stage (to see additive-factors method interpretations of results, see Sternberg 1966; Sternberg, 1969b). Sternberg's work has played an important role in demonstrating the power of response times in understanding mental processes.

Numerous imagery studies emerged during the cognitive revolution (Arnheim, 1969; Bower, 1972; Bugelski, 1970; Hebb, 1968; Holt, 1964; Horowitz, 1970; Reese, 1970; Richardson, 1969; Segal, 1971; Sheehan, 1972; Shepard & Feng, 1972). A particularly notable study was reported by Paivio (1971; see also Paivio, 1969; Paivio & Csapo, 1971). Paivio investigated whether verbal and visual memory representations produced similar patterns in response times. In Paivio's experiment, participants were required to remember a series of either pictures or words in a study phase, then recall the pictures/words in a separate test phase of the experiment. Paivio observed that pictures were better remembered than words when items in the test phase were presented in a random order relative to the presentation order of the study phase. However, when the test items were presented in the same order across study and test phases, words were better remembered than pictures. In a separate study, Paivio and Csapo (1969) demonstrated that when items were presented quickly in the study phase, memory for pictures was inferior to words, leading researchers to conclude that efficient memory of pictures depends on the transformation of pictures to words. Paivio further suggested that words and pictures differed in their initial processing codes, leading to different organization in memory. These different processing codes may lend themselves to different types of tasks – for example, the nature of a picture code may be organized in a way that allows for efficient processing of spatial relations, while the word codes may be organized better for rote memory.

Another seminal imagery study was reported by Kosslyn (1975). Participants were instructed to imagine pairs of animals standing next to each other. The first animal was always a fly or elephant and the second animal (i.e., the target animal) varied in size from a mouse to a small dog. Following this imagery task, a property of an animal was presented to the participants, and they had to evaluate whether that property appropriately fit the target animal. For example, an animal-property pair like 'cat' and 'claws' would require a *true* response, whereas an animal-property pair like 'dog' and 'beak' would require a *false* response. If representations constructed with visual imagery are like those in the real world, then a mental image where a target animal is paired with the elephant should result in a zoomed-out picture relative to when the target animal is paired with the fly. As a result, it should take longer to scrutinize a feature of the target animal when it is smaller (i.e., paired with the elephant) than when it is larger (i.e., paired with the fly). Across several experiments, it was demonstrated that imagined representations produced the predicted pattern of results – responses were faster and more accurate when the target animal was paired with the fly than the elephant. These results support the notion that the 'mind's eye' operates much like the visual system.

A similar finding was demonstrated by Kosslyn, Ball, and Reiser (1978; see also Kosslyn, 1973; Lea, 1975). Participants were required to generate a mental image of a map of an island with several landmarks that was shown to them earlier in the experimental session. Once the map was generated, participants were presented with a landmark that was followed either by another landmark on the map or a sensible landmark name that was not included on that map. Participants were then instructed to generate imagery that focused on the location of the first landmark then mentally scan to the second landmark and provide a button press response once they arrived. The researchers observed that the time to respond whether the second landmark was on the map increased with its distance from the first landmark. The researchers interpreted this finding to suggest imagined representations operated similar to a perceptual map, such that when the location of the first and second landmarks were nearby, participants were able to more quickly orient to the location than when the landmarks were further away.

Another important imagery study was reported by Shepard and Metzler (1971; see also Attneave, 1974; Cooper & Shepard, 1973; Shepard & Cooper, 1982). In this study, participants were shown two 3-dimensional shapes. These two shapes were constructed such that they were either the same shape or the mirror opposite, and the critical manipulation was the degree to which the view point of the display of these shapes differed. The task was then to determine whether these two shapes were either the same or different. Shepard and Metzler observed that the speed at which participants performed this task depended on the angular degree difference in view point between the two shapes; response times increased linearly with the angular difference of the view point. Based on follow-up experiments, Shepard and Metzler argued that response times directly map on to the time it takes to rotate the shapes in mind, further supporting the notion that the operations of the 'mind's eye' are similar to that of the perceptual world.

Not all research at this time supported the conclusions that visual imagery is fundamentally similar to perception (Brainerd, 1971; Brown, 1958; Gibson, 1966; Neisser, 1972). One of the most prevalent arguments against this notion was forwarded by Pylyshyn (1973; see also Pylyshyn, 1981; 2002; 2003). Directly influenced by developments in computer science (Newell, Shaw, & Simon, 1957), Pylyshyn proposed that mental events are represented in a propositional form. Pylysyhyn argues that imagery effects, like those described earlier (i.e., mental rotation, scanning, etc.), are driven by tacit knowledge of how the task ought to be performed – this argument was used to discredit the pictorial view of mental scanning tasks (Kosslyn, Ball, & Reisser, 1978) and the size of mental images task (Kosslyn, 1973). Specific to mental rotation tasks (i.e., Shepard & Metzler, 1971), Pylyshyn (2002, p. 165) writes:

> Even if the process of making the comparison in some sense involves the 'rotation' of a representational shape, this tells us nothing about the form of the representation and does not support the view that the representation is pictorial. The proposal that a representation maintains its shape because of the inherent rigidity of the image while it is rotated cannot be literally true, …the representation is not literally being rotated; no codes or patterns of codes are being moved in a circular motion.

Pylyshyn (1979) further argues that the imagery-based mental rotation accounts are limited since mental rotation tasks are affected by complexity of the figure and rotation task (Carpenter, 1976; Reed, 1974), claiming that mental rotation cannot occur independent of other processes, and thus, cannot be purely due to rotation as would occur in the perceptual world.

This classic imagery debate is not the focus of this thesis. Though the results presented in the thesis offer some support to the notion that imagined representations share properties with perceptual representations, it does not address the broader issue of explicit operations that support mental representations. Nonetheless, it is worthwhile to highlight briefly some limitations of the propositional theory. A key limitation of the propositional theory is that it provides only post hoc explanations of the behavioral results of imagery tasks – that is, it does not put forth predictions that can or have ever been empirically tested. To date, there is no direct evidence in support of the propositional theory, and while it is true that behavioral results often cannot differentiate between pictorial and propositional theories, neuroimaging results appear to be unanimously in support of the pictorial theories of imagery (Farah, 1988; 1989; Farah, Peronnet, Gonon, & Giard, 1988; Tootell, Silverman Switkes, & De Valois, 1982; Kosslyn, Ganis, & Thompson, 2001; Kosslyn, Thompson, & Ganis, 2006). Further, pictorial theorists have established explicit theories that have nicely fit subsequent behavioral findings (Kosslyn & Promerantz, 1977; Kosslyn, 1981; Kosslyn, Thompson, & Ganis, 2006), while the propositional theorists have not done the same. Instead, they have accounted for each new imagery finding by modifying propositional accounts to fit the data (see Pylyshyn, 2002). Anderson (1978) notes that the propositional theorists can and will always find a way to modify their theory to explain imagery effects, irrespective of parsimony.

Color imagery

Despite numerous imagery studies, there are few color imagery studies. An early color imagery study is that of Finke and Schmidt (1977; see also Allan, Siegel, Collins & MacQueen, 1989; Finke, 1980; Ganis & Schendan, 2008). Here, Finke and Schmidt used color imagery to explore what is called the McCollough effect. The McCollough effect is a context-specific color image aftereffect. For example, if you were to stare at a vertical grating of red bars for a sufficient period of time, when you looked away from this image you would then see a faint afterimage of its opponent color, green. This process allows for better visual acuity in environments dominated by a color by increasing activation of the opponent color (e.g., the light conditions at dusk). The McCollough effect is a color image aftereffect like that just described, except that this color image aftereffect changes based on the context in which the colors were observed (McCollough, 1965). For example, if you were to show an image with red and black vertical gratings then an image with yellow and black horizontal gratings, and these images were shown back and forth over a sufficient period of time, when you were shown images that replace the red and yellow colors with white, you would see a green afterimage over the white vertical gratings and a blue afterimage over the white horizontal gratings. McCollough (1965) proposes that these orientation-specific color aftereffects result from the selective adaptation of horizontal and vertical edge detectors.

Finke and Schmidt (1977) explored whether this orientation-specific color aftereffect could also be produced when color imagery was generated in place of colors. Participants were shown vertical and horizontal grating patterns except that they were always white and black. Participants were instructed prior to the experiment to imagine a color in the white space of the gratings, with a different color imagined for vertical and horizontal gratings (e.g., red for vertical gratings, yellow for horizontal gratings). Participants then reported the color of their color image aftereffect. Finke and Schmidt showed an effect opposite to that of the McCollough effect – that is, participants more frequently reported seeing the color they were instructed to imagine than the opposite. In contrast, when participants were instructed to imagine vertical and horizontal gratings onto solid colored backgrounds, Finke observed a weaker version of the McCollough effect. Finke's results suggest that imagery can produce the McCollough effect, however these imagery effects are produced by context rather than by color. Though color imagery failed to produce the McCollough effect, it did produce a color imagery bias, which supports the broader claim that color imagery-based facilitation effects in perception are possible (though see Broerse & Crassini, 1980; 1981; Zhou & May, 1993).

Several studies have explored color imagery ability following brain injury. Bartolomeo, Bachoud-Levi, and Denes (1997) had participants with damage to their anterior inferior occipital regions with intact primary visual cortices perform a series of tasks. One such task was a perceptual color discrimination task that required participants to arrange a series of color patches in a rainbow-like configuration. In another task, participants were required to indicate the color of a specific object presented to them verbally. It was observed that these participants performed poorly on the perceptual color discrimination task, and performance was unimpaired in the color imagery task. Bartolomeo et al. concluded that participants were relying on imagined representations to perform the imagery task, as opposed to non-visual knowledge-based representations of the object (see also, Chetterjee & Southwood, 1995; de Vreese, 1991; Goldenberg, Mullbacher, & Nowak, 1995; Shuren, Brott, Scheft, & Houston, 1996; Zago et al., 2010). In a similar study, Goldenberg (1992) showed that a patient with temporo-occipital damage had difficulty indicating the color of an object in an imagery task similar to that described, but showed unimpaired perceptual color discrimination. Together, these results suggest that there are specific processes underlying color imagery, and that these processes may differ from those that support perception.

There have also been several studies that explored imagery using neuroimaging measures (Ishai et al., 1999; O'Craven & Kanwisher, 2000; Slotnick, Thompson, & Kosslyn, 2005). Specific to color, some studies have shown that brain regions early in the visual processing stream are activated during imagery (Cui, Jeter, Yang, Montague, & Eagleman, 2007; Hsu, Frankland, & Thompson-Schill, 2012; Rich et al., 2006; Simmons et al., 2007; Kosslyn & Thompson, 2003). On the other hand, some studies have shown that color imagery does not depend on activity in early visual processing areas (Bramao, Faisca, Reis, & Peterson, 2010; Chao & Martin, 1999; Howard et al., 1998; Lu et al., 2010). In the first neuroimaging study on color imagery, Howard et al. (1998) demonstrated similarities and differences between perceptual and imaginal networks during color imagery. They showed that color perception activated the posterior fusiform gyrus bilaterally in area V4, as well as the right anterior fusiform and lingual gyri, striate cortex (V1) and the insula. On the other hand, color imagery activated the right anterior fusiform gyrus, left insula, right hippocampus and the parahippocampal gyrus – note, not the V4 or V1 regions. However, Hsu, Frankland, and Thompson-Schill (2012) demonstrated that color imagery resulted in activity of the V4 region, as did perception, and that color perception simply activated a larger region of V4 than was the case for imagery (see also Bergmann, Genc, Kohler, Singer, & Pearson, 2015).

More recently, color imagery has been explored using binocular rivalry tasks (Chang, Lewis, & Pearson, 2013; Pearson, Clifford, & Tong, 2008; Pearson, Rademaker, & Tong, 2011; Pearson & Kosslyn, 2015). Binocular rivalry is a phenomenon that occurs when different retinoptically overlapping images are shown to each eye. Under these conditions, only one of these images is visible to the observer at a time, and the visibility of these images flips back and forth across time. Chang, Lewis, and Pearson used a binocular rivalry procedure to assess whether color imagery could influence visual bias in binocular rivalry tasks. Participants were shown different colors to each eye and they indicated the color that was immediately visible. Prior to each trial of this binocular rivalry task, a color cue (e.g., 'red') was presented to each eye and participants imagined the cued color in a blank interval prior to a trial of the binocular rivalry task. Chang, Lewis, and Pearson observed that participants more frequently reported a bias for the color they were cued to imagine than the other color. Interestingly, passive viewing of the color patch resulted in a visual bias that was smaller than those produced by color imagery. In a separate series of experiments, Pearson, Rademaker, and Tong (2011) showed that this imagery binocular rivalry effect was modulated by self-reported strength of color imagery, suggesting that the visual bias was not simply produced by the semantic property of the imagery cues.

In another recent color imagery study, Reinhart, McClenahan, and Woodman (2015) explored whether practiced visual search with imagery could enhance visual search performance (though see Clarke, Barr, & Hunt, 2016). In the search task, a target cue was displayed prior to the search array and the task was to indicate whether the target was present or absent in the search array. This task was performed in 5-trial long sequences, where the target remained the same across the sequence. The control group participants simply performed the search task, while the imagery group participants were not shown the search array for the first three trials of the sequence, and were instructed to imagine performing the search task with the target instead. Reinhart et al. observed that search task responses of the control group participants were increasingly fast over the course of the 5-trial sequence. Interestingly, participants in the imagery group performed as well as those in the control group, despite not performing the search task for the first 3-trials in the trial sequence. This result suggests that imagined practice may produce similar results to actually performing the task. Further, electrophysiological measures suggested that more imagery training resulted in attention being more efficiently focused on the target. Overall, this finding demonstrates that visual attention mechanisms can be effectively trained to select targets in the absence of visual input.

Another example of the impact of color imagery on visual search has been demonstrated by Moriya (2018). Moriya used color imagery to evaluate whether it could influence processes associated with attentional capture in visual search. Participants were shown two colored Landolt Cs on either side of fixation, one with the gap on the top or bottom (i.e., the target) and the other with the gap on the right or left (i.e., the distractor). Participants were instructed to indicate the side of the Landolt C with the gap positioned on either the top or bottom of the stimulus, and then to provide a key-press corresponding to this gap location. Prior to this search task, participants were presented with a word cue that indicated a color (e.g., ‘blue’, ‘red’), and were required to imagine this color in the blank interval prior to the search task. Moriya observed that when color imagery was congruent with the target stimulus, participants responded faster than when the imagery color matched the distractor stimulus, and faster also than when the imagined color was absent from the display. Further, Moriya demonstrated that when the imagined color and the distractor colors were congruent, responses were slower than when the color was absent from the search display. This result suggests color imagery does not simply benefit search performance by facilitating target discrimination, but that it also leads to inefficient search performance when imagery is congruent with the distractor.

Color imagery has also been demonstrated to enhance color identification (Wantz, Borst, Mast, and Lobmaier (2015). Wantz et al. presented one of six color patches (i.e., red, orange, yellow, green, blue, or brown) centrally and participants had to identify the color by pressing a corresponding response key. Prior to each trial of the color identification task, participants were cued to imagine a color corresponding to the one of the six color patches they would observe later in the trial. They were cued to imagine the color either with the first two letters of the color (e.g., ‘re’, ‘or’, ‘ye’, ect.) or with gray scale images of objects that typically corresponded with the color (e.g., lemons, strawberries, etc.). Wantz et al. observed that participants performed the color identification task faster when they imagined a color congruent with the target color than when the imaged a color incongruent with the target color. Wantz et al. suggested that color imagery primed perceptual representations in a manner similar to that reported in studies of perceptual priming. It should be noted, however, that this interpretation is subject to criticism in this thesis – to foreshadow the results, this imagery effect did not occur when a response bias interpretation of the results was controlled for (Chapter 3).

Visual search and the Priming of Pop-out effect

As stated at the outset, this thesis examines how color imagery impacts several different perceptual effects. The first effect discussed here is one observed in visual search tasks. Visual search tasks involve the scan of the visual environment for a particular object or feature (i.e., targets) among other objects or features (i.e., distractors; Treisman & Gelade, 1980). Practical examples of visual search can be seen in everyday life, such as when one is scanning a crowd for a friend or an animal is searching for berries amongst the foliage. Though visual search can be measured in a number of different ways, visual search efficiency is commonly measured using response time. That is, the response time required to search for a target amidst distractors is taken to reflect the efficiency with which the search is performed.

There are a number of different types of visual search that vary based on the features of the search array. One particular type of visual search is known as conjunctive search. Here, participants are required to identify a target surrounded by distractors that possess one or more common visual features with the target. The key to most conjunctive search tasks is that there is no single feature that distinguishes between the target and the array of distractors. An example of a conjunctive search task is having a person search for a red 'X' (i.e., the target) amongst distractors composed of green 'X's and red 'O's. What makes conjunctive search unique is that the efficiency of performance depends on the number of distractors – that is, as the number of distractors increases, response time also increases (Bacon & Egeth, 1997; McElree & Carrasco, 1999; Wolfe, 1998). Treisman and Gelade (1980) suggested that this distractor set size effect occurs because search for the target requires the integration of feature representations across two or more brain regions, and such an integration process requires spatial attention to be shifted serially across all items in the display. In other words, conjunctive search requires that each object in the search display be attended so that its features can be integrated and then evaluated until the target is identified.

Another form of visual search is singleton search. Singleton search tasks are sometimes known as feature search tasks, and they involve identifying a target among an array of distractors based on a unique feature, such as color, shape, orientation, or size. An example of a singleton search task is having participants search for a red 'X' among green 'X's. Unlike conjunctive search tasks, in singletons search tasks the number of distractors present in the array has little impact on the search efficiency, such that the target appears to 'pop out' amongst the distractors.

With respect to the feature integration theory proposed by Triesman and Gelade (1980), here it is thought that singleton search does not require integration across brain regions, and as such, search can be performed in parallel across all objects in the search array.

A phenomenon in singleton search tasks of particular interest here is the Priming of Pop-out (PoP) effect. PoP is an effect that reflects particularly efficient performance when the target and distractor colors remain the same across consecutive trials of a singleton search task. For example, if the singleton oddball target on one trial is a red diamond amongst green diamonds, participants respond faster when on the next trial the target is once again a red diamond amongst green diamonds than if the singleton target is now a green diamond amongst red diamonds. Bravo and Nakayama (1992) were the first to introduce the method in which target and distractor colors in a singleton search task alternated unpredictably on a trial-by-trial basis. Using this method they demonstrated that response times were consistently faster for repeat trials than for switch trials.

Maljkovic and Nakayama (1994; 1996; 2000) explored the PoP effect further. The most notable theoretical contribution of Maljkovic and Nakayama is their proposal that the PoP effect is driven by passive and automatic processes that are unaffected by top-down strategies. This point is best demonstrated by Experiments 3 and 4 of Maljkovic and Nakayama (1994). In Experiment 3, participants performed singleton search tasks in which the target was always the oddball color among homogenously colored distractors. The primary manipulation in this experiment was the probability with which the target and distractor colors repeated across trials relative to when they switched. The idea here is that if top-down strategic processes influence the PoP effect, then a high likelihood of target colors switches should reduce the magnitude of the PoP effect due to strategic preparation for the upcoming switched target color. To evaluate this hypothesis, participants performed blocks of singleton search trials in which the likelihood that the target color repeated and switched across trials varied across blocks; the target colors switched across trials either 0%, 50%, 70%, 90% or 100% of the time. Here, Maljkovic and Nakayama observed that regardless of the target color switch likelihoods, participants were consistently faster for repeat trials relative to switch trials – that is, the PoP effect was unaffected by the likelihood of the target color. Maljkovic and Nakayama concluded that participants were unable to use top-down strategic processes to override the PoP effect.

Maljkovic and Nakayama (1994) further explored whether top-down strategy can influence the PoP effect in Experiment 4. Participants were again required to find the oddball colored target, however, target color repeat and switch trials were now intermixed in a perfectly predictable pattern (i.e., red, red, green, green, red, red, etc.). In the passive condition, participants were made aware of this predictable trial sequence and were instructed to simply respond to the target. In the active condition, participants were instructed to subvocalize the upcoming target color in the interval prior to the singleton search array. The idea here was that this subvocalization task would ensure participants were aware of the identity of the upcoming target color. Maljkovic and Nakayama once again observed a significant PoP effect in both the passive and active conditions. Importantly, the response time difference between switch and repeat trials was not different in the passive and active conditions, suggesting that there was no weakening of the PoP effect in the active condition relative to the passive condition. Maljkovic and Nakayama concluded from these experiments that the PoP effect reflects the passive and automatic persistence of short-term memory representations.

Several other theorists have also forwarded accounts for the PoP effect. Hillstrom (2000; see also, Huang, Holcombe & Pashler, 2004; Thomson & Milliken, 2011, 2012, 2013) proposed that faster responses for repeat trials than switch trials depends on the retrieval of episodic representations for which the stored feature bindings match those needed to perform the current search task. As such, the episodic view assumes that the PoP effect is not due to enhanced attentional processing, but rather reflects a form of improved decision-related processing. In other words, participants are faster to respond when the target and distractor colors remain consistent across trials because they are faster at interpreting the odd-colored object as being the target. Another theory proposes that the PoP effect works to resolve stimulus ambiguity (Meeter & Olivers, 2006), as the PoP effect only occurs when the target needs to be disambiguated across trials. Other studies suggest that the PoP effect may have more than one cause, and may be influenced by more than one cause simultaneously within a single task (Becker, 2008; Lamy, Yashar, & Ruderman, 2010; for a review see, Kristjansson & Campana, 2010).

Most of the literature suggests that the processes driving the PoP effect are not influenced by top-down processes (though see Fecteau, 2007). However, it remains possible that top-down processes can influence the PoP effect, but that prior experiments have not identified a top-down processing manipulation that is sufficient to do so (see Muller & Krummenacher, 2006; Theeuwes, Reimann, & Mortier, 2006; Wolfe, Horowitz, Kenner, Hyle, & Vasan, 2004). As detailed in the color imagery section of the thesis, color imagery has been shown to influence brain regions associated with perceptual processing. If the processes responsible for the PoP effect tap into these same perceptual processing regions, we expect to find that color imagery can override representations responsible for the PoP effect. Further, it may be that top-down strategies that fail to engage perceptual regions of the brain adequately do not influence the PoP effect. To foreshadow some of the results presented later in this thesis, we find that color imagery does engage processes responsible for the PoP effect, and that comparable verbal tasks do so to a lesser degree or not at all. This issue will be explored in Chapters 1 and 2 of the thesis here.

Color discrimination tasks and event file binding effects

Another type of experimental procedure explored here focuses on color discrimination. A classic finding using discrimination tasks is that when a cue is presented prior to a target, discrimination responses are faster when the cue and target are the same than when they are different (Beller, 1971; Posner & Mitchell, 1967; Rosch, 1975). The first study to use a cue-target color discrimination task was reported by Rosch (1975). In this study, Rosch displayed a color patch to participants for a short duration. Participants were then required to perform a color discrimination task for a following color target that either matched or mismatched the preceding color patch. Rosch demonstrated that when the color target of the discrimination task matched the preceding color cue they were faster to respond (i.e., the facilitation effect) than if the target mismatched the preceding cue.

Further studies of these facilitation effects have demonstrated that they can often depend on a complex relationship between stimulus and response features (Hommel, 1998; Pashler & Baylis, 1991). A particular phenomenon that highlights this complex relationship is that of object file updating. Object files are proposed to be short-term episodic representations of real world objects (Kahneman & Treisman, 1984). They are thought to consist of transient links across brain regions that bind features of an object (i.e., color, shape, location, etc.) processed in distinct brain regions. These links lead to efficient processing when a task requires the identical bindings of this feature information from one trial to the next. Behavioral evidence of object files was first explicitly demonstrated by Kahneman, Treisman, and Gibbs (1992). Here, participants were required to respond to a target letter that matched both the location and identity of the preceding letter, or matched the identity of one preview letter and the location of a different preview letter. Naming responses were faster for the condition in which the target matched both location and identity of a preview letter, implicating some form of memory for the binding between the location and identity features.

The findings of Kahneman, Treisman, and Gibbs (1992) are supported by feature integration theory (Treisman and Gelade, 1980), which proposes that visual stimuli are processed in two distinct stages: a pre-attentive stage and a focal attention stage. In the pre-attentive stage, features are registered automatically and in parallel across all stimuli in the visual field. This pre-attentive stage of processing is presumed to underlie phenomena like the pop-out effects in visual search described in the previous section. In the focal attention stage, the allocation of attention to an object results in the integration of features into an object file. Object specific preview benefits are then produced when responses to an object is facilitated by retrieval of these feature bindings.

More recently, the breadth of these binding processes have been expanded to include associated actions (Hommel, 1998; Hommel, Musseler, Aschersleben, & Prinz, 2001). Hommel (1998) displayed an ‘X’ or ‘O’ on screen, and participants provided a key-press response based on an arrow cue (*left* or *right*) that was presented earlier in the trial. Participants then performed a target discrimination task, indicating by key-press whether the target was an ‘X’ or ‘O’. Importantly, the key-press responses following the cueing task and the target discrimination task overlapped to produce stimulus-response (S-R) bindings that matched, mismatched, or partially matched. Hommel observed that performance on the target discrimination task depended critically on these S-R bindings. Specifically, responses were fast when both the cue identity and response perfectly matched the target identity and response, or when the cue identity and response perfectly mismatched the target identity and response. Performance was slow in comparison when there was a partial match of S-R bindings across the cue and target discrimination tasks. This result suggests that it is not only perceptual features that contribute to object files, but action-related information (Hommel, 2004; Hommel & Colzato, 2004; Hommel et al., 2001).

The theory of event coding (TEC; Hommel et al., 2001) was forwarded to explain these and other related findings. According to TEC, stimulus and response features are coded by independent and distributed networks (Hommel, 2009; Hommel & Colzato, 2004), and the integration of these representations produces what they call an 'event file'. Much like the proposal of Kahneman et al. (1992), TEC proposes that when a new stimulus shares a feature with the event file of a preceding stimulus, that event file is automatically retrieved and updated with the new stimulus information. A perfect match between the new stimulus and retrieved event file results in efficient updating and performance. However, when the new stimulus matches the event file on one feature but mismatches on another (i.e., a partial match), updating is much less efficient resulting in a performance cost. When all features of a new stimulus mismatch with the event file of the preceding stimulus, a new event file is created rather than updating the preceding event file, a process that is typically more efficient than event file updating for a partial match.

Both feature integration theory and TEC involve the integration of representations across distributed brain networks. These binding processes are presumed to involve stimulus features processed in regions of the brain associated with perception. However, if imagery engages the same brain regions as perception, then imagery representations ought to be subject to the same types of binding processes. The issue of whether representations supported by imagery can contribute to event file binding processes is explored in Chapter 4 of this thesis.

Color discrimination tasks and event mediated inhibition effects

Apart from the event-file binding effects described in the previous section, stimulus repetition can also produce facilitation effects. One of the first instances of such a facilitation effect was demonstrated by Bertelson (1961). Two light-bulbs were displayed in front of the participant, and if the left lightbulb turned on, participants were required to provide a *left* button response. If the right lightbulb turned on, participants were required to make a *right* button response. Bertelson observed that when the target location repeated across trials, participants were faster to respond than when the target location switched across trials. These target-to-target facilitation effects have been demonstrated using many experimental procedures (Kirby, 1976; Kornblum, 1973; Maljkovic & Nakayama, 1994; Rabbitt, 1968).

Inhibition effects are also commonly reported in studies of stimulus repetition. A notable example of an inhibition effect was reported by Law, Pratt, and Abrams (1995). They used a cue-target procedure in which a color patch was displayed prior to a detection task that required participants to indicate the presence of a second color patch with the press of the spacebar. The cue and target were either the same or different colors (red or blue). On some trials, an irrelevant magenta color patch was displayed in the interval between presentation of the cue and target and on other trials the irrelevant magenta color patch was absent. An inhibition effect – faster responses to targets that mismatched cues than to targets that matched cues – was observed only when the magenta color patch was presented between cue and target.

The results of Law et al. (1995) were subsequently extended to a target-to-target color discrimination procedure. Spadaro, He, and Milliken (2012) instructed participants to indicate with a key-press whether a target rectangle was blue or yellow for each of two consecutive displays on each trial. On some trials these target colors matched and on other trials the target colors mismatched. An intervening event (a red dot) was displayed in the temporal interval between these two targets on some trials and not on others, and participants pressed the spacebar in response to the intervening event. In keeping with the study of Law et al., an inhibition effect was observed only when an intervening event appeared between consecutive targets. A facilitation effect was observed when no intervening event appeared between targets.

The precise processes underlying these effects are still debated. Law et al. (1995) proposed that inhibition might be guided by the same processes as guide the Inhibition of Return (IOR) effect. In a typical IOR task, participants are presented with a peripheral cue that orients attention automatically to its location. A target then appears at the location of the cue or at some other location. When the temporal interval between cue and target is relatively short (typically less than 300 ms), participants are faster to respond to the target when it appears at the same location as the cue than when it appears at a different location. When the duration of the interval between cue and target is longer, participants are instead faster to respond when the target appears at a different location than the cue – the IOR effect. Law et al. proposed that non-spatial inhibition effects involving color stimuli could engage the same set of orienting processes as underlie spatial IOR effects. Although a quite different theoretical account, Lupiáñez (2010) has also proposed that non-spatial inhibition effects may be produced by the same mechanisms as those that produce spatial IOR effects (see also Hu, Samuel, and Chan, 2010; Hu & Samuel, 2011; Hu, Fan, Samuel, & He, 2013).

At the same time, other research suggests that spatial IOR effects and non-spatial inhibition effects may be driven by different processes (Taylor & Klein, 1998). In particular, Taylor and Klein proposed that intervening event based inhibition effects may be a form of repetition blindness, an effect by which participants frequently miss the second presentation of a repeated stimulus when it is presented soon after the first one (Kanwisher, 1987; 1991; see also Fox & de Fockert, 2001; but see Riggio, Patteri & Umilta, 2004)

Regardless of the precise cause of non-spatial inhibition effects, a recent study by Hilchey, Rajsic, Huffman, and Pratt (2017) demonstrates that these effects are unaffected by the binding processes described in the previous section. Hilchey et al. (2017) demonstrated that subtle changes in the location of the target and intervening event eliminated the inhibition effect. However, the resulting data were identical to those often observed in studies of event binding (Notebaert & Soetens, 2003; Rajsic, Bi, & Wilson, 2014). In other words, non-spatial inhibition effects and event binding processes appear to make separate contributions to performance.

In summary, although it is not clear exactly what processes underlie the non-spatial facilitation and inhibition effects described here, it is quite clear that they are driven by different processes than those that produce event binding effects (Chapter 4). Nor are they driven by processes responsible for the attention effects observed in visual search tasks (Chapters 2 and 3). As such, the third empirical issue addressed in this thesis is whether the non-spatial facilitation and inhibition effects can be produced when participants are required to imagine a color rather than view it perceptually. If color imagery engages the same processes as color perception, then an inhibition effect ought to be observed when an intervening event is presented temporally between the color imagery and color discrimination tasks, whereas a facilitation effect may be observed when there is no intervening event between color imagery and color discrimination tasks. This topic will be explored in Chapter 5.

Chapter 2: An Imagery Induced Reversal of Intertrial Priming in Visual Search

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Preface

Chapter 2 presents the results of 5 experiments where the influence of color imagery on the Priming of Pop-out effect was examined. The general method was that participants were required to indicate the side of a missing gap on an oddball color singleton surrounded by homogenously colored distractors. Between search trials that were presented in pairs, participants were required to imagine a color opposite to the target on the first trial in the temporal interval prior to the second. In Experiment 1a and 2a, we replicated the basic finding that when target colors were repeated across trials, participants were faster than when it was switched with distractors. These experiments also revealed that when participants were required to imagine an opposite color in the interval between trials, they were faster to colors that matched imagery than colors that matched the previous target. In Experiments 1b and 2b, we replicated the basic imagery effect and also showed that saying the color aloud instead of generating color imagery did not produce the same effect. In Experiment 3, we attempted to evaluate whether color imagery impacted the same processes that guided intertrial priming effects. Here, the results were unclear – the overall data suggested that color imagery and intertrial priming effects were driven by different processes, and the trials in which participants reported strong imagery suggested that they were driven by the same processes.

Abstract

Maljkovic and Nakayama (1994) found that pop-out search performance is more efficient when a singleton target feature repeats rather than switches from one trial to the next – an effect known as Priming of Pop-out (PoP). They also reported findings indicating that the PoP effect is strongly automatic, as it was unaffected by knowledge of the upcoming target color. In the present study, we examined the impact of visual imagery on the PoP effect. Participants were instructed to imagine a target color that was opposite that of the preceding trial (e.g., if the prior target was red, then imagine green). Under these conditions, responses were faster for targets that matched the imagined color than for targets that matched the previous target color, reversing the typical PoP effect. There was no such reversal of the PoP effect for participants asked to verbalize rather than imagine an upcoming target color. In Experiment 3, we explored whether the PoP effect was indeed eliminated in the prior experiments, or instead obscured by the opposing visual imagery effect. Two conditions were compared, one in which a PoP effect could oppose the visual imagery effect, and another in which no such effect was possible, allowing inferences about whether a PoP effect was or was not present. The results indicated that the PoP effect was present, but that it was negligible when self-reported visual imagery was strong. Overall, the results suggest that the processes driving the PoP effect are sensitive to top-down strategies that involve visual representations.

Introduction

The goal of a visual search task is to find a target object among non-target (distractor) objects. Treisman and Gelade (1980) found that when the target and distractors differ by a single feature (e.g., a red ‘T’ among blue ‘T’s), search performance is relatively insensitive to the number of distractors in the search display; that is, the target appears to ‘pop out’ from the distractors. Thus, whereas difficult visual search tasks appear to require slow, serial shifts of attention across the visual display, pop-out search is commonly attributed to automatic, pre-attentive processes.

If pop-out search in vision were strongly automatic, then one might expect it to be affected only by visual factors. One domain of research that challenges this view examines trial-to-trial influences on pop-out search efficiency. Bravo and Nakayama (1992) introduced a method in which target and distractor colors in a pop-out search task alternated unpredictably on a trial-by-trial basis. For example, a red target with green distractors on one trial could be followed by either a red target with green distractors (a repeat trial) or a green target with red distractors (a switch trial). Using this method, Maljkovic and Nakayama (1994) demonstrated that response times (RTs) were faster for repeat trials than for switch trials, an effect they called Priming of Pop-out (PoP).

The PoP effect implies that pop-out search is not driven entirely by visual factors, and that it can be affected by the persistence of visual memory representations. Indeed, in their seminal study Maljkovic and Nakayama (1994) concluded that PoP effects are caused by the persistence of short-term visual memory representations that influence target saliency in an implicit and automatic manner. A key piece of evidence that favors this view is that top-down expectation often produces only a modest effect, or in some cases no effect at all, on PoP. The present study introduces a new method of measuring the influence of expectation on PoP effects that capitalizes on visual imagery. To foreshadow the results, we demonstrate robust visual imagery induced expectation effects on PoP. Indeed, we demonstrate that these effects are sufficiently strong to reverse the PoP effect.

Expectation and the PoP effect

Maljkovic and Nakayama (1994) conducted two experiments to investigate the impact of expectation on the PoP effect. In Experiment 2 of their study, observers searched for an odd-colored diamond that was either red or green on each trial and indicated whether it was missing a chunk on either the left or right side. The percentage of target color switch trials varied by block, with each of the following percentages being implemented: 0%, 50%, 70%, 90%, and 100%. In the 0% condition, the target color remained the same for the entire block while in the 100% condition the target color switched between all trials in the block. Maljkovic and Nakayama reasoned that if expectation impacts PoP, then RTs ought to vary across these conditions in accord with an inverted-U shape function. In other words, observers ought to have responded fastest when the target color was most predictable (when target color switches occurred on either 0% or 100% of trials) and slowest when the target color was least predictable (when target color switches occurred on 50% of trials). Rather than this inverted-U function, Maljkovic and Nakayama found that RTs increased steadily as the percentage of target color switches increased. They concluded that expectations about the percentage of target color switches did not aid performance in the search task.

In a separate experiment, Maljkovic and Nakayama (1994; Experiment 4) again asked observers to find an odd-colored diamond and indicate whether it was missing a chunk on either the left or right side. However, in this experiment they intermixed target color repeat and target color switch trials in a perfectly predictable sequence (i.e., red, red, green, green, red, red, green, green…etc.). In the 'passive' condition, observers were instructed simply to respond to the target. In the 'active' condition, observers were instructed to subvocalize the upcoming target color in the interval prior to the presentation of the search array. Given the perfectly predictable sequence of target colors, observers were able to subvocalize the upcoming target color on both repeat and switch trials with perfect accuracy. Nonetheless, responses were faster for repeat trials in both the passive and active conditions. More important, the RT difference between switch and repeat trials was no different in the passive and active conditions, which suggests that there was no weakening of the PoP effect in the active condition relative to the passive condition. Maljkovic and Nakayama concluded again that top-down expectation did not influence the PoP effect in this experiment, and more generally that the PoP effect reflects the implicit, automatic persistence of short-term visual memory representations.

Other studies that have explored the role of expectation in studies of the PoP effect have revealed mixed results. Hillstrom (2000) compared PoP effects across two conditions that differed in predictability; the perfectly predictable condition described above, and a condition in which the target color and distractor color alternated unpredictably from trial-to-trial. The PoP effect was larger for the perfectly predictable condition than for the random condition, suggesting that expectancy can in fact impact trial-to-trial repetition effects. In line with this result, Geyer and Muller (2009) found that cumulative repetition trial benefits (when the target and distractor color remain unchanged for long runs of trials) were larger when runs were more likely. However, in the same study they found that first-order repetition benefits (faster responses when the target matches the previous target, but not the target two trials prior) were not sensitive to the likelihood of a trial-to-trial repetition. Sigurdardottir, Kristjansson, and

Driver (2008) also reported a study suggesting that cumulative repetition trial benefits owe to changes in perceptual sensitivity across long runs of repeated target trials rather than changes in conscious expectation (for similar results see Asgeirsson and Kristjansson, 2014). Together, these results lend doubt as to whether expectation does or does not influence trial-to-trial repetition effects in pop-out search tasks.

In a recent study, Thomson, D'Ascenzo, and Milliken (2013) varied the relative proportions of repeat and switch trials across blocks in a pop-out search task similar to that employed by Maljkovic and Nakayama (1994). In one block of trials, 80% of the trials were target color repeats and 20% were target color switches, whereas in another block the opposite was the case (i.e., 20% repeats, 80% switches). Importantly, this percentage repeat manipulation was implemented within pairs of trials that were each separated by four seconds. This method ensured that cumulative repetition benefits would not confound the comparison of PoP effects measured across 80% repeat and 20% repeat blocks. Nonetheless, they found that the PoP effect was larger in the 80% repeat block than in the 20% repeat block, consistent with the idea that expectation can impact first-order trial-to-trial repetition effects. At the same time, the PoP effect in the 20% repeat block remained significant; that is, participants were still faster for rare target repeat trials than for common target switch trials. In line with the conclusions of Maljkovic and Nakayama (1994), this result highlights the idea that the PoP effect is strongly influenced by the representation of the prior target, and perhaps only weakly controlled by expectancy. If trial-to-trial repetition effects were instead strongly controlled by expectancy, we might expect responses to be faster for the more frequent switch trials than the less frequent repeat trials.

On the other hand, it may be that prior studies have demonstrated only weak control of PoP effects by expectancy because the expectancy manipulations themselves have been weak. For example, Thomson et al. (2013) did not inform participants of the different percentage repeat conditions, and the subjective report of participants gave no indication that they became aware of this manipulation, implying that they were unlikely to have used this knowledge strategically. Although it is clear that Maljkovic and Nakayama's (1994) 'active' participants were aware of the perfectly predictable double alternating sequence, and that they used this knowledge to generate a subvocal prediction of the following target color, it seems less clear that this subvocal prediction constitutes an optimal method of generating an expectation in a visual search task. In other words, for expectations to impact performance in a visual search task, the expectation might well have to be visual in nature.

Visual Imagery, Expectation, and PoP

The notion that visual expectancies can influence visual search is rooted firmly in the subjective experience of searching in real world contexts. When looking for a friend in a crowd it feels as if we configure attention to optimize search, for example by constructing a visual template that describes what the friend is wearing that day (Wolfe, 1994, Wolfe, Cave & Franzel, 1989). The notion that visual representations guide visual search is also well supported empirically. For example, Wolfe, Horowitz, Kenner, Hyle, and Vasan (2004) used a procedure in which feature conjunction search targets were cued at varying temporal intervals prior to onset of search displays. When the cues were exact visual replicas of the targets, and even for very short cue-target temporal intervals, search performance was almost as efficient as in a control condition in which the targets remained fixed across all trials in a block. In contrast, verbal cues were much less effective at guiding search, even for well-learned stimulus properties, and with long temporal intervals that allowed for substantial preparation between cue presentation and onset of the search display.

A similar issue was examined in a study of pop-out search performance by Theeuwes, Reimann, and Mortier (2006). They presented participants with search displays in which the target was unpredictably either a singleton shape or a singleton color. The key research question was whether cueing participants with the singleton dimension ahead of time would affect search performance. Verbal cues did not produce a reliable cue validity effect, whereas cues that were exact visual replicas of the singleton target did produce a cue validity effect. At the same time, Theeuwes et al. (2006) attributed the cue validity effect for exact visual replica cues to bottom-up priming processes like those described in studies of the PoP effect (Maljkovic & Nakayama, 1994) rather than to top-down control over singleton search. Nonetheless, these results highlight the important role of visual representations in guiding search.

Cuing the target of search with a visual replica of the target does introduce a form of visual expectancy to visual search tasks. However, returning to the example of finding a friend in a crowd, we are unlikely to consult a picture of a friend to guide search, and instead more likely to self-generate a visual representation to guide search. Self-generated visual imagery is commonly reported to be perception-like – it appears to be available to the mind's eye. Although there is a vast literature on visual imagery itself (for a review, see Kosslyn, Thompson & Ganis, 2006), the influence of visual imagery on visual search has not been studied extensively. One exception is a recent study by Reinhart, McClenahan, and Woodman (2015). Participants in this study were instructed to imagine search for a particular target amidst distractors for two trials followed by actual search for the same target amidst distractors. The results revealed superior actual search performance in this imagery condition than in a comparable condition in which participants performed actual visual search on all trials. In effect, this study illustrated that visual imagery can produce learning that transfers to visual search.

Beyond the visual search domain, there are a small number of additional studies that suggest visual imagery can impact representations involved in visual perception. For example, it has been shown that color visual imagery prior to a binocular rivalry task can bias vision in favor of color representations that match the prior imagery (Pearson, Clifford, & Tong, 2008; Chang, Lewis, & Pearson, 2013). Similarly, color visual imagery prior to a color identification task can produce faster identification times for targets that match rather than mismatch the imagined color (Wantz, Borst, Mast, & Lobmaier, 2015). Together with the results of the Reinhart et al. (2015) study, these results suggest that visual imagery can produce profound effects in a range of visual perception tasks.

The aim of the present study was to re-visit whether trial-to-trial effects in pop-out search are sensitive to expectancy, with a specific emphasis on expectancy formed with visual imagery. To that end, we examined the influence of expectancy on trial-to-trial repetition effects in pop-out search under conditions in which: (1) participants were given clear instructions to adopt a strategic expectancy, and (2) the instructed strategic expectancy emphasized visual rather than verbal representations.

Experiment 1A

Participants in Experiment 1A were required to respond to a color pop-out target on one trial, and then to imagine a target object of a different color in the temporal interval leading up to onset of the following trial. The critical issue was whether pop-out search for the second trial in each pair would be driven by the target color from the first trial, or by the imagined color generated by the participant following the first trial.

Method

Participants. Thirty undergraduates at McMaster University (26 female, M_{age} = 20.9 years) took part in exchange for course credit. Fifteen of the 30 participants were assigned randomly to each of the control and imagine groups. All participants reported normal or corrected-to-normal vision.

Apparatus and stimuli. Stimuli were presented using Psychopy v1.82 on a BenQ 24-in LED monitor that was connected to a Dell 300 computer. The search displays contained one target square and four distractor squares, each of which subtended vertical and horizontal visual angles of 2 degrees. Targets were differentiated from distractors by their color; the target was red and distractors were green, or vice versa. All displays were presented on a black background. On each search trial, each of the five squares was randomly assigned to 1 of 8 locations that were equidistant from the center of the screen. The distance from center of the screen to each of these locations subtended a visual angle of 5 degrees. All squares contained a gap in either the left or right side that subtended a visual angle of 0.5 degrees.

Procedure. Participants were seated approximately 57 cm from the computer screen. On each trial one target and four distractor squares were presented.[1] Participants were asked to locate the odd-colored square on each trial and to indicate as quickly and accurately as possible whether it had a gap in the left or right side. Participants indicated a *left* response by hitting the ‘z’ key with their left index finger and a *right* response by hitting the ‘m’ key with their right index finger. The search display remained on the screen until the participants made a response.

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[1] In a similar study by Thomson et al. (2013), a single target square was presented with two rather than four distractor squares. There was no particular reason for incorporating this difference in method in the present study, but it is worth noting that increasing the number of distractors can weaken the PoP effect (Meeter & Olivers, 2006).

Trials were presented in pairs. Each pair began with a black screen with a central fixation across displayed for 500 ms followed by a first search trial as described above. Following a response from the participant to the first trial in a pair, a black screen with a central fixation cross was displayed for 2000 ms. After this interval a second trial was presented. Following response to this second trial, a black screen with white text stating ‘press the spacebar when you are ready to continue’ was presented. When ready, participants then could continue on with the next trial pair by pressing the *spacebar*. The purpose of this trial structure with a break between trial pairs was to allow participants to prepare as needed prior to self-initiating each trial pair. A typical trial pair is depicted in Figure 1.

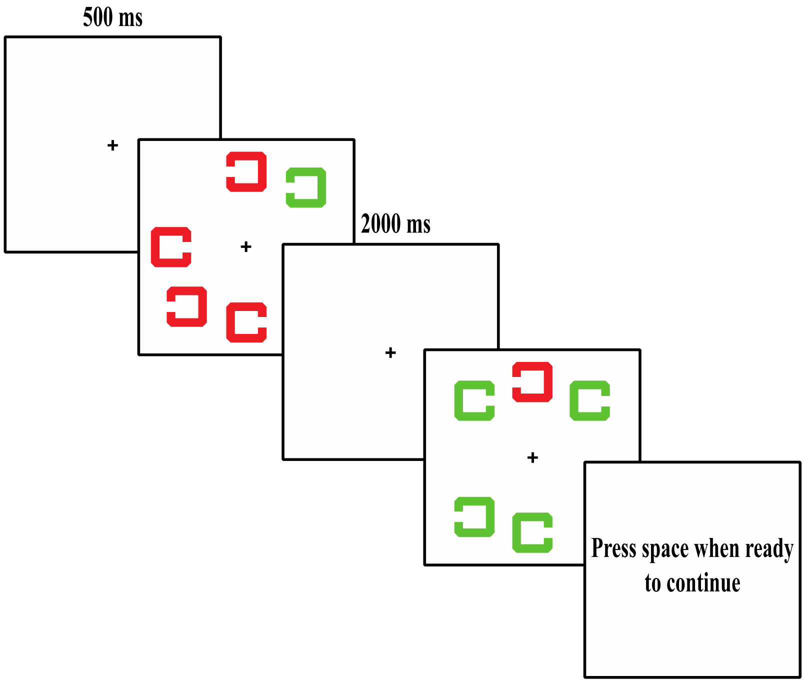

Figure 1. An example of a trial pair sequence. Participants in the imagine groups of Experiments 1A, 1B, 2A, and 2B, and those in the imagine-opposite condition of Experiment 3 were instructed to imagine a square that was opposite the color of the target of the first trial during the interval between trial pairs. Participants in the control groups of Experiments 1A and 2A were given no such instruction. Participants in the verbal groups of Experiments 1B and 2B were instructed to say aloud a color name that was opposite the target color of the first trial during the interval between trial pairs.

The experiment began with 15 practice trial pairs to ensure that participants fully understood the instructions prior to starting the experimental trials. The experimental session consisted of 75 trial pairs. Participants were invited to complete the entire experimental session, but were also reminded that they were not obliged to complete the entire experimental session. Also, participants were told that the maximum duration of the experimental session would be 15 minutes. Nonetheless, all participants completed all 75 trial pairs within the designated time.

Participants were randomly assigned to either the imagine group or the control group. In the imagine group, participants were instructed to imagine a square that was opposite the color of the target in the first trial in each pair prior to the onset of the second search display. For example, if the target in the first trial was red and the distractors were green, participants were instructed to imagine a green square, and vice versa. In the control group, participants were given no such instruction. That is, participants in the control group simply responded to the target on the first trial in a pair, and then again to the target on the second trial in a pair. A questionnaire was given to participants in the imagine group after the experimental session. The purpose of the questionnaire was to assess how often (i.e., on what percentage of the trials) participants engaged in the visual imagery task as instructed. Otherwise the procedures for the imagine and control groups were identical.

Overall, the design of this experiment included two independent variables: color sequence (switch/repeat) and group (imagine/control). On switch trials, the target color changed across trials within a trial pair, whereas on repeat trials, the target color remained the same across trials within a trial pair. As noted above, participants in the imagine group were instructed to imagine an opposite colored square between trials in each trial pair, whereas participants in the control group were not given this instruction to imagine. Importantly, the relative percentages of repeat and switch trials in the experimental session were set at 20% and 80%, respectively.

A primary concern in developing the procedure described above was that the visual imagery task for participants in the imagine group would be demanding on cognitive resources. Importantly, if the visual imagery task was too demanding, participants might not engage in visual imagery consistently, as instructed, on all trials across the experimental session. For this reason, experimental sessions were relatively short (i.e., just 75 trial pairs), and trial pairs were self-initiated allowing participants to take a break after each trial pair. In addition, participants were given thorough instructions, and practice sessions to ensure that they understood the instructions. Practice sessions for both groups began with five trial pairs prior to which participants were simply instructed on how to respond to targets in each search display. Participants in both groups were then given another five trial pairs with the explicit instruction that switch trials occurred 80% of the time. For the final five trial pairs in the practice session, participants in the imagine group only were instructed to imagine a square of the opposite color to the previous target in the interval between trials within each trial pair. Participants in the control group were given no additional instructions for the final five trial pairs. All participants were tested one at a time and were encouraged to ask questions to ensure they understood the instructions. Following the practice session, it was emphasized to participants that it was important for them to follow task instructions as best as possible. All experiments reported in this article received ethics clearance though the McMaster Research Ethics Board.

Results

Correct RTs on each trial for each condition were first submitted to an outlier analysis that eliminated any suspiciously slow or fast RTs from further analysis. The outlier analysis used was the non-recursive outlier elimination procedure of Van Selst and Jolicoeur (1994), which ensures that different proportions of observations are not systematically excluded from cells with different numbers of observations. This outlier analysis resulted in the elimination of 3.1% of the observations from further analyses. Mean correct RTs were computed from the remaining observations, and these mean RTs and corresponding error rates were submitted to mixed factor ANOVAs that treated color sequence (repeat/switch) as a within-subject variable and group (control/imagine) as a between-subjects variable. Mean RTs collapsed across participants are displayed in Figure 2. Error rates are displayed in Table 1. An alpha level of .05 was used to determine statistical significance in all analyses reported below.

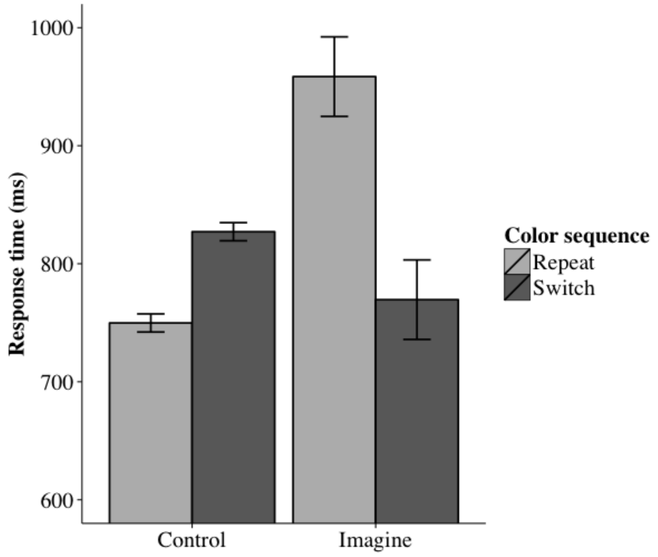

Figure 2. Mean response times for repeat and switch trials in the control and imagine groups in Experiment 1A. Error bars represent the standard error of the mean corrected to remove between-subject variability (Cousineau, 2005; Morey, 2008).

Table 1. Mean error percentages (%) across experiments.

	Experiment 1A Group	
	Control	Imagine
Repeat	2.44	2.50
Switch	1.64	2.68
	Experiment 1B Group	
	Verbal	Imagine
Repeat	0.33	2.45
Switch	2.28	2.03
	Experiment 2A Group	
	Control	Imagine
Repeat	1.09	2.90
Switch	1.57	3.09
	Experiment 2B Group	
	Verbal	Imagine
Repeat	0.54	1.72
Switch	1.67	3.16
	Experiment 3 Condition	
	New	Opposite
Incongruent	4.56	7.28
Congruent	4.75	5.46

The analysis revealed a significant interaction between group and color sequence, $F(1, 28) = 22.29$, $p < .001$, $\eta^2_p = .44$. This interaction was examined further by analyzing the effect of color sequence separately for the control and imagine groups. For the control group, the effect of color sequence was significant, $F(1, 14) = 38.02$, $p < .001$, $d = .57$. Responses for repeat trials (750 ms) were significantly faster than those for switch trials (827 ms). This result constitutes a replication of the typical PoP effect. For the imagine group, the effect of color sequence was also significant, $F(1, 14) = 11.81$, $p = .004$, $d = 1.13$, but in this case responses were faster for switch trials (770 ms) than for repeat trials (959 ms; see Figure 2).[2]

There were no significant effects in the analysis of error rates, and the pattern of error rates does not support a speed-accuracy trade-off interpretation of the RT results.

Discussion

The purpose of Experiment 1A was to re-examine the influence of expectancy on the PoP effect (Maljkovic & Nakayama, 1994). To address this issue, participants in the imagine group were instructed to perform a visual imagery task following the first trial in a trial pair; specifically, they were asked to imagine a square that was opposite in color to the target to which they had just responded. These participants produced faster responses when the target color switched across trials in a trial pair than when the target color repeated across trials in a trial pair. In other words, when participants performed the visual imagery task, they showed the opposite of the PoP effect. To our knowledge, this is the first demonstration that the PoP effect can be reversed with a strategic expectancy.

Further, participants in the control group produced faster responses when the target color repeated across trials in a trial pair relative to when the target color switched across trials in a trial pair. This result constitutes a replication of Thomson et al. (2013), who also reported a significant PoP effect with the percentage of target switch trials set at 80% and the percentage of

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[2] Mean correct RTs for each group (control/imagine) were also submitted to separate paired t-tests that assessed the effect of color sequence (repeat/switch) across trial pairs; that is, from the second trial in one trial pair to the first trial in the following trial pair. The primary purpose of this analysis was to examine whether the reversal of the PoP effect reported above for the imagine group was restricted to the color sequence within trial pairs, when participants had been instructed to imagine the opposite color. In the imagine group, the difference between repeat (873 ms) and switch (907 ms) trials was not statistically significant, but the trend was similar to that reported above for the control condition rather than the imagine condition. This result demonstrates that the reversal of the PoP effect was indeed restricted to the color sequences within trial pairs. In the control group, responses were significantly faster for repeat trials (720 ms) than for switch trials (812 ms), $t(14) = 7.11$, $p < .001$, $d = .82$.

target repeat trials set at 20%. In other words, the higher likelihood of a target color switch than a target color repeat in and of itself did not eliminate the PoP effect.

Experiment 1B

The purpose of Experiment 1B was to compare the impact of visual and verbal strategic expectancies on the PoP effect. If visual expectancies of the type implemented in Experiment 1A more strongly influence the PoP effect than do verbal expectancies, then this might explain the discrepancy between the results of the imagine group in Experiment 1A and the results of Maljkovic and Nakayama's (1994; Experiment 4) active expectancy group. To address this issue, two groups were tested in Experiment 1B: an imagine group identical to that of Experiment 1A and a verbal group. Participants in the verbal group were instructed to say aloud the color name that was opposite the target color of the first trial during the interval between trials in each trial pair.

Method

Participants. Thirty undergraduates at McMaster University (20 female; $M_{\text{age}} = 18.2$) took part in exchange for course credit. Fifteen of the 30 participants were assigned randomly to each of the verbal and imagine groups. All participants reported normal or corrected-to-normal vision.

Apparatus and stimuli. The apparatus and stimuli were identical to those used in Experiment 1A.

Procedure. The procedure was similar to that in Experiment 1A with the exception that participants were randomly assigned to either the imagine group or the verbal group. Instructions for the imagine group were identical to those given in Experiment 1A. Instructions for the verbal group were similar to those given to the imagine group with the exception participants were instructed to say aloud rather than imagine the opposite target color in the 2000 ms interval between trials in a trial pair. Participants in both groups were given a questionnaire following the experiment to assess the proportion of trials on which they engaged in these strategies.

Results

Correct RTs were submitted to the same outlier elimination procedure as in Experiment 1A, which eliminated 2.8% of the observations from further analyses. Mean correct RTs and error rates were computed from the remaining observations and submitted to mixed factor ANOVAs that treated color sequence (repeat/switch) as a within-subject variable and group (verbal/imagine) as a between-subjects variable. Mean RTs collapsed across participants are displayed in Figure 3, and error rates are displayed in Table 1.

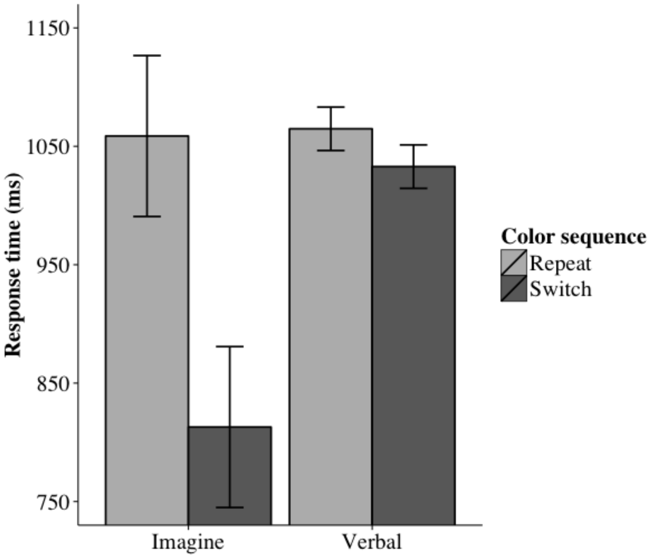

Figure 3. Mean response times for repeat and switch trials in the verbal and imagine groups in Experiment 1B. Error bars represent the standard error of the mean corrected to remove between-subject variability (Cousineau, 2005; Morey, 2008).

The analysis of RTs revealed a significant main effect of color sequence, *F*(1, 28) = 5.84, $p = .02$, $\eta^2_p = .17$. Responses were faster for switch trials (921 ms) than for repeat trials (1062 ms). However, this effect was qualified by an interaction between color sequence and group that approached significance, *F*(1, 28) = 3.46, *p* = .07, η^2_p = .11. Given our a priori interest in whether the imagine group replicated the pattern of results observed in Experiment 1A, and in whether a similar result would be observed in the verbal group, we examined this interaction further by analyzing the simple main effects of color sequence separately for the imagine and verbal groups. For the imagine group, the effect of color sequence was significant, *F*(1, 14) = 4.91, *p* = .04, *d* = .65. Responses in the imagine group were significantly faster for switch trials (813 ms) than for repeat trials (1059 ms). For the verbal group, the effect of color sequence was not significant; response times for switch trials (1033 ms) were not statistically different from those for repeat trials (1065 ms).[3]

There were no significant effects in the analysis of error rates, and the pattern of error rates does not support a speed-accuracy trade-off interpretation of the RT results.

Discussion

The primary purpose of Experiment 1B was to compare the influence of visual and verbal strategic expectancies on the PoP effect. There were two critical results. First, participants in the imagine group once again responded faster to switch trials than to repeat trials. This result constitutes an important replication of the result observed for the imagine group of Experiment 1A. Second, participants in the verbal group did not produce this reversal of the PoP effect. Given the different results observed for the imagine and verbal groups, we conclude that the

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[3] As in Experiment 1A**,** mean correct RTs for each group (verbal/imagine) were submitted to separate paired t-tests that assessed the impact of color sequence (repeat/switch) across trial pairs; that is, from the second trial of one trial pair to the first trial in the following trial pair. In the imagine group, the difference between repeat (1031 ms) and switch (1040 ms) trials was not significant, but again the trend was opposite that described above for the within trial pairs comparison. A similar result was observed for the verbal group; the difference between repeat (1101 ms) and switch (1118 ms) trials was not significant.

visual imagery strategy had a stronger impact than the verbal strategy on processes that mediate the PoP effect.

At the same time, it does appear that the verbal strategy had an impact on performance, as there was no hint of the usual PoP effect for this group. It is unclear why the verbal strategies used by our participants impacted the PoP effect, whereas the subvocal verbal strategy used by participants in Maljkovic and Nakayama's (1994, Experiment 4) appeared not to affect the PoP effect at all. There are several methodological differences between the two studies that will have to be examined in future studies to address this issue. Nonetheless, the results from both of the experiments reported to this point are consistent with the view that visual strategies produce strong expectancy effects that can reverse the PoP effect.

Experiment 2A

In Experiments 1A and 1B the target color switched between trials in a trial pair 80% of the time and repeated 20% of the time. These proportions of trial types were designed to encourage participants to use the strategy of imagining the opposite target color following the first trial in each pair. The present experiment was identical to Experiment 1A with the exception that switch and repeat trials were equally likely. The goal of this experiment was to examine whether the pattern of results observed in Experiment 1A would generalize to a procedure in which the proportions of repeat and switch trials were not aligned with the visual imagery strategy. We suspected that the high proportions of trial pairs in which the imagined color matched the target in Experiment 1A might have incentivized participants to use the visual imagery strategy, and that therefore any effect of imagery in the present experiment would likely be smaller in magnitude. To address this issue, we increased the sample size from 30 to 48 participants.

Methods

Participants. Forty-eight undergraduates at McMaster University (30 female; M_{age} = 18.8) took part in exchange for partial course credit. Twenty-four of the 48 participants were assigned randomly to each of the control and imagine groups. All participants reported normal or corrected-to-normal vision.

Apparatus and stimuli. The apparatus and stimuli were identical to those used in Experiments 1A and 1B.

Procedure. The procedure was similar to that in Experiment 1A with the following exceptions. The percentage of both repeat and switch trial types was set at 50%. Participants were no longer informed of the percentage of switch and repeat trials. Practice trials used to demonstrate the percentages of repeat and switch trials were also removed, leaving a total of 10 practice trials.

Results

Correct RTs were submitted to the same outlier elimination procedure as in Experiments 1A and 1B. This procedure excluded 2.7% of observations from further analyses. Mean correct RTs and error rates were computed from the remaining observations and submitted to mixed factor ANOVAs that treated color sequence (repeat/switch) as a within-subject variable and group (control/imagine) as a between-subjects variable. Mean RTs are displayed in Figure 4, and error rates are displayed in Table 1.

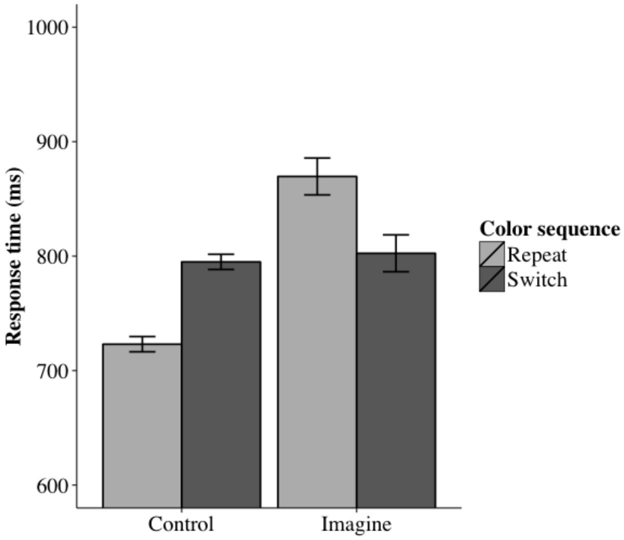

Figure 4. Mean response times for repeat and switch trials in the control and imagine groups in Experiment 2A. Error bars represent the standard error of the mean corrected to remove between-subject variability (Cousineau, 2005; Morey, 2008).

The analysis of RTs revealed a significant interaction between group and color sequence $F(1, 46) = 23.86$ $p < .001$, $\eta^2_p = .34$. The interaction was examined further by analyzing the simple main effects of color sequence separately for the control and imagine groups. For the control group, the effect of color sequence was significant $F(1, 23) = 43.90$, $p < .001$, $d = .37$. Responses for repeat trials (723 ms) were faster than for switch trials (795 ms). For the imagine group, the effect of color sequence was also significant, $F(1, 23) = 6.51$, $p = .02$, $d = .22$. In this case, responses for repeat trials (870 ms) were slower than for switch trials (802 ms).

There were no significant effects in the analysis of error rates, and the pattern of error rates does not support a speed-accuracy trade-off interpretation of the RT results.[4]

Discussion

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[4] The correct RTs for each group (control/imagine) were submitted to separate paired t-tests that assessed the impact of color sequence (repeat/switch) from the second trial of one trial pair to the first trial of the following trial pair. In the control group, there was a significant difference between repeat trials (714 ms) and switch trials (820 ms), $t(23) = 6.55$, $p < .001$, $d = .46$. In the imagine group, there was no difference between repeat (1053 ms) and switch (1084 ms) trials, but again the trend was in the direction of faster responses for repeat trials.

The primary purpose of Experiment 2A was to assess whether the visual imagery strategy would result in a reversal of the conventional PoP effect when switch and repeat trials occurred with equal probability. Indeed, as in Experiments 1A and 1B, participants in the imagine group responded faster to switch trials than to repeat trials. In contrast, and as observed in Experiment 1A, participants in the control group produced the conventional PoP effect: responses were faster to repeat trials than to switch trials.

Experiment 2B

The purpose of Experiment 2B was to compare the impact of visual and verbal strategic expectancies under conditions in which the proportions of repeat and switch trials were not biased in favour of the instructed visual imagery strategy. As such, the procedure in this experiment was identical to that for Experiment 1B, with the exception that the percentages of repeat and switch trials were equal.

Methods

Participants. Forty-eight undergraduates at McMaster University (35 female; M_{age} = 19.1) participated in exchange for partial course credit. Twenty-four of the 48 participants were assigned randomly to each of the verbal and imagine groups. All participants reported normal or corrected to normal vision.

Procedure. The procedure for Experiment 2B was identical to that of Experiment 1B with the exception that the percentage of both repeat and switch trials was set at 50%. As in Experiment 2A, participants were not given information regarding the percentages of repeat and switch trials, and practice trials used to demonstrate the percentages of repeat and switch trials were removed, leaving a total of 10 practice trials.

Results

Correct RTs for each condition were submitted to the same outlier analysis as in prior experiments, which resulted in the exclusion of 2.5% of observations from further analysis. Mean RTs collapsed across participant are displayed in Figure 5, and error rates are displayed in Table 1.

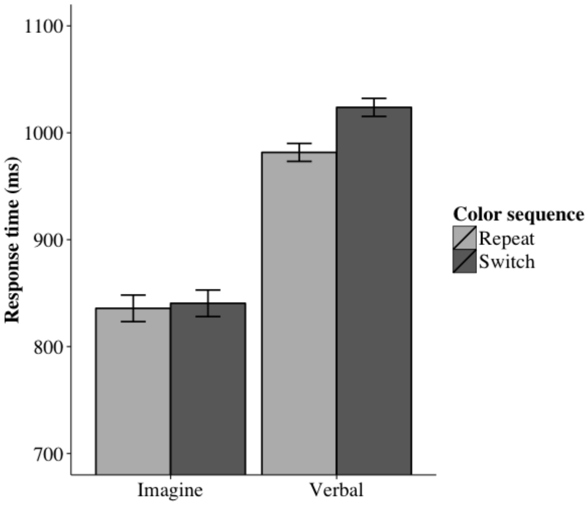

Figure 5. Mean response times for repeat and switch trials in the verbal and imagine groups in Experiment 2B. Error bars represent the standard error of the mean corrected to remove between-subject variability (Cousineau, 2005; Morey, 2008).

The analysis of RTs revealed that the interaction between group and color sequence was not significant, $F(1, 46) = 2.25$, $p = .14$, $\eta^2_p = .05$. Nonetheless, we had an a priori interest in the repetition effects for each group, and therefore analyzed the simple main effects of color sequence separately for each group. In the verbal group, the effect of color sequence was significant, $F(1, 23) = 9.40$, $p = .006$, $d = .20$. Responses were faster for repeat trials (982 ms) than for switch trials (1023 ms), a replication of the PoP effect. In the imagine group, there was no difference between repeat trials (836 ms) and switch trials (840 ms; see Figure 5).[5]

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[5] The correct RTs for each group (verbal/imagine) were submitted to separate paired t-tests that assessed the impact of color sequence (repeat/switch) from the second trial in one trial pair to the first trial in the following trial pair. In the verbal group, there was a significant difference between repeat trials (1002 ms) and switch trials (1105 ms), $t(23)$

The only significant effect in the analysis of error rates was the main effect of color sequence, $F(1, 46) = 8.83$, $p = .005$, $\eta^2_p = .16$. In line with the response times from this experiment, the error rates were higher for switch trials than for repeat trials (see Table 1).

Discussion

The primary purpose of Experiment 2B was to compare the influence of visual and verbal strategies on the PoP effect under conditions in which switch and repeat trials occurred in equal proportions. One critical result was that participants in the verbal group responded faster to repeat trials than to switch trials. This result demonstrates that verbalizing a target color prior to onset of a search display will not invariably speed performance for search targets that match the verbally produced color (see also Maljkovic and Nakayama, 1994; Experiment 4). A second critical result, one that differed from Experiment 2A, concerned performance for the imagine group. Although the visual imagery strategy appears to have eliminated the PoP effect in this experiment, the reversal of the PoP effect observed in Experiments 1A, 1B, and 2A was not observed here. An explanation for the results of the imagine group in this experiment is clearly required.

A challenge in conducting these experiments is that there is no guarantee that participants will consistently use the visual imagery strategy provided to them. Further, even if use of the visual imagery strategy does produce a reversal of the PoP effect, any trials in which participants do not use the visual imagery strategy are bound to produce the usual PoP effect. Thus, if an analysis includes a mixture of trials in which the visual imagery strategy was used on some trials but not on other trials, then the resulting mixture of PoP effects with reverse PoP effects might lead to a null priming effect overall. Similarly, if an analysis includes a mixture of participants,

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= 5.23, $p < .001$, $d = .43$. In the imagine group, there was also a significant difference between repeat trials (884 ms) and switch trials (948 ms), $t(23) = 2.74$, $p = .02$, $d = .27$.

with some using the visual imagery strategy and others not using the visual imagery strategy, then one is also likely to observe a null priming effect overall. To address this concern, we instructed participants in the imagine group to give a percentage estimate of the proportion of trials in which they used the visual imagery strategy. A comparison across experiments showed that participants' subjective estimates of visual imagery strategy use were higher in Experiments 1A (81%), 1B (79%) and 2A (78%) than in Experiment 2B (73%). This result suggests that there may have been lower visual imagery strategy use in Experiment 2B than in the other experiments. To address this possibility, and to get as accurate a picture as possible of performance in the imagine groups of Experiments 2A and 2B, the data from the imagine groups for these two experiments were pooled together, and a split-half analysis was conducted based on participants' subjective reports of the percentage of trials in which they used the visual imagery strategy. The resulting mean subjective estimate of visual imagery strategy use for the frequent strategy users was 88%, whereas for the infrequent strategy users this mean was 62%. Mean RTs were then submitted to a mixed factor ANOVA that treated color sequence (repeat/switch) as a within-subject variable and imagery use (high/low) as a between-subjects variable. Mean RTs collapsed across participants are displayed in Figure 6.

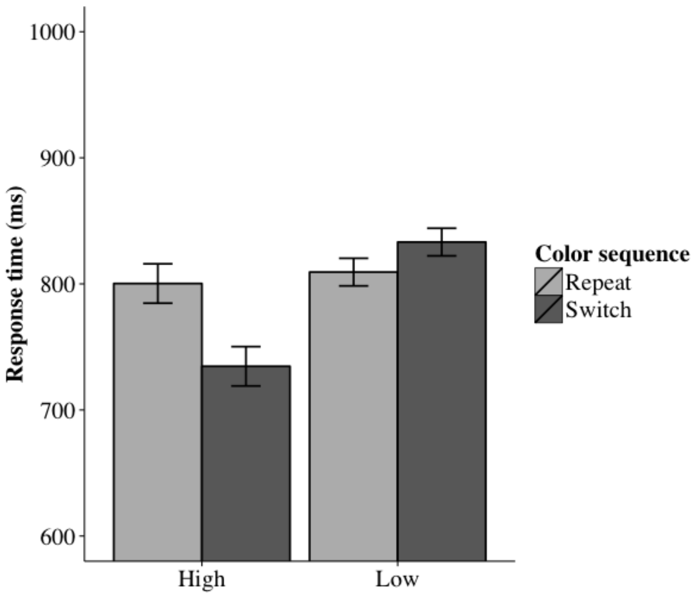

Figure 6. Mean response times for participants in the imagine group of Experiments 2A and 2B, divided into high and low users based on a median split of their subjective estimates of imagine strategy use. Error bars represent the standard error of the mean corrected to remove between-subject variability (Cousineau, 2005; Morey, 2008).

The analysis revealed an interaction between imagery use and color sequence that was significant, $F(1, 46) = 8.26$, $p = .006$, $\eta^2_p = .15$. Separate analyses of the repetition effect for the high and low imagery use groups were then conducted using a Bonferroni adjusted alpha level of .025 to determine statistical significance. For the high imagery use group, the effect of color sequence was significant, $F(1, 23) = 6.64$, $p = .02$, $d = .36$. Responses for switch trials (735 ms) were significantly faster than those for repeat trials (800 ms). In contrast, for the low imagery use group, there was no difference between switch trials (833 ms) and repeat trials (809 ms). The important result here is that participants who did claim to use the visual imagery strategy most in Experiments 2A and 2B produced a significant reversal of the PoP effect.[6]

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[6] To examine this relation between the PoP effect and self reported imagery use further, a similar analysis was conducted for Experiments 1A and 1B. The resulting mean subjective estimate of visual imagery strategy use for the frequent strategy users was 88%, whereas for the infrequent strategy users it was 70%. Mean RTs were then submitted to a mixed factor ANOVA that treated color sequence (repeat/switch) as a within-subject variable and

Experiment 3

The reversal of the usual PoP effect produced by participants in the imagine groups of preceding experiments implies that strategic use of visual imagery can affect pop-out search performance. However, this reversal of the usual PoP effect does not necessarily imply that strategic expectancy on its own controls performance. Rather, it remains possible that an automatic influence of the preceding target color that speeds responses for repeat trials contributes to performance together with a strategic imagery process that speeds responses for switch trials (see Theeuwes & Van der Burg, 2011). By this view, the reversal of the usual PoP effect would occur when the strategic imagery process is stronger than the automatic visual memory process. The goal of the present experiment was to tease apart these two potential contributing processes to performance.

To address this issue, we introduced a condition in which the first trial of a trial pair used one set of target and distractor colors (red and green), while the second trial of a trial pair used a second set of target and distractor colors (yellow and purple). Participants were given imagery instructions to imagine a yellow square if the first target was red, and to imagine a purple square if the first target was green. In this manner, targets matched or mismatched with the imagery generated by participants, and the influence of this match/mismatch with imagery could be measured. Most important, performance in this condition measured the influence of strategic expectancy (i.e., imagery) in the absence of an automatic process that speeds performance for repeats relative to switches. In contrast, performance in the conventional condition used in all

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imagery use (high/low) as a between-subjects variable. The split-half analysis revealed an interaction between group and color sequence that approached significance, *F*(1, 28) = 2.98, *p* = .10, $\eta^2_p = .10$. Separate analyses of the color sequence effect for the high and low strategy use groups were then conducted using a Bonferroni adjusted alpha level of .025 to determine statistical significance. There was a marginally significant effect of color sequence for those in the high strategy use group, *F*(1, 14) = 5.38, *p* = .04, *d* = .64, with faster responses for switch trials (785 ms) than for repeat trials (1044 ms). In contrast, there was no significant difference between switch trials (824 ms) and repeat trials (876 ms) for those in the low strategy use group.

prior experiments reported here could, in principle, measure both strategic expectancy that speeds performance for switches and an opposing automatic process that speeds performance for repeats. Both conditions were included in this experiment, which allowed us to compare the effect of expectation under conditions in which an opposing automatic process may or may not be present.

Methods

Participants. Thirty-two undergraduates at McMaster University (23 female; M_{age} = 19.4) participated in exchange for partial course credit or monetary compensation. All participants reported normal or corrected to normal vision.

Procedure. Participants completed two conditions that were counter-balanced across blocks. In the imagine-opposite condition, participants were given instructions that were identical to those of the imagine group in Experiments 1A and 1B with the following exceptions. Participants were now required to assess the quality of their visual imagery following each trial pair on a rating scale that ranged from 1 to 4, such that '1' indicated 'no imagery', '2' indicated 'some imagery', '3' indicated 'moderate imagery', and '4' indicated 'strong imagery almost like perception.' Participants indicated their rating with a key press corresponding to each of the numbers. Participants were also given instructions on how to respond to the visual imagery probe during the practice session of the experiment. In the imagine-new condition, the target and distractor colors changed between trials in a trial pair such that the colors in the first trial in a pair were always red and green, while the colors in the second trial in a pair were always yellow and purple. Rather than instructing participants to imagine the opposite color of the previous target, participants were instructed to imagine 'a yellow square' if the first target was red, and 'a purple square' if the first target was green. If the target in the first trial in a pair was red, 80% of the time the target in the second trial in a pair would be ‘yellow’ and 20% of the time it would be purple. If the target in the first trial in a pair was green, 80% of the time the target in the second trial in a pair would be ‘purple’ and 20% of the time it would be yellow. Participants in the imagine-new condition were also required to rate the quality of their visual imagery following each trial pair. Participants were required to complete 150 trials (75 trial pairs) per condition for 300 total trials (150 trial pairs). There was a practice session of 15 trials for each condition. A typical trial pair of the imagine-new condition is depicted in Figure 7.

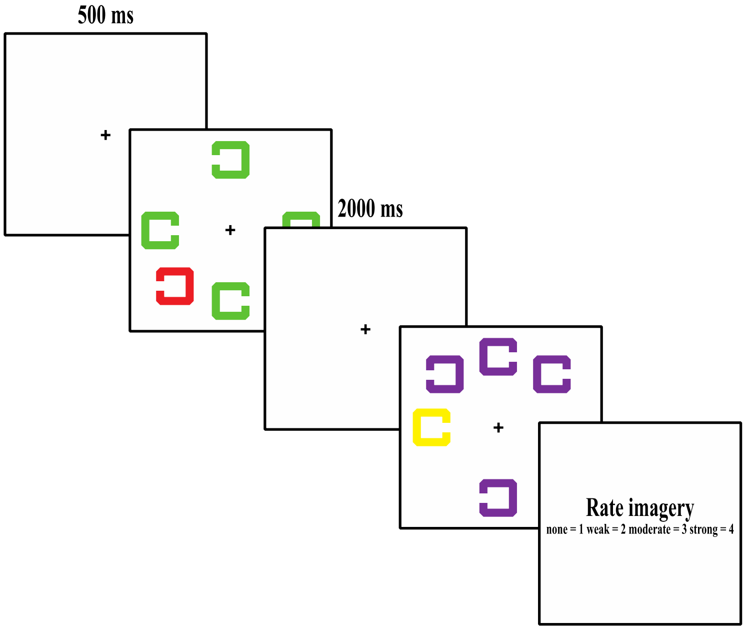

Figure 7. An example of a trial pair sequence for the imagine-new condition of Experiment 3. In the imagine-opposite condition of Experiment 3, participants performed the task shown in Figure 2, but also rated their imagery following each pair of trials as shown in this figure.

Results

Correct RTs were submitted to the same outlier analysis as in prior experiments, which resulted in the exclusion of 3.0% of observations from further analysis. Mean correct RTs were computed from the remaining observations. The mean correct RTs and corresponding error rates were submitted to within-subject ANOVAs that treated trial type (congruent/incongruent) and condition (imagine-opposite/imagine-new) as within-subject variables. Note that we use the terms congruent and incongruent here to refer to the relation between the imagined color and the following target color. This terminology is required by the imagine-new condition in which the first trial colors were red and green, and the second trial colors were yellow and purple (i.e., there were no repeat/switch trials in this condition). For the imagine-opposite condition, the congruent condition in this experiment corresponds to the switch condition in prior experiments, whereas the incongruent condition corresponds to the repeat condition in prior experiments. Mean RTs collapsed across participants are displayed in Figure 8.

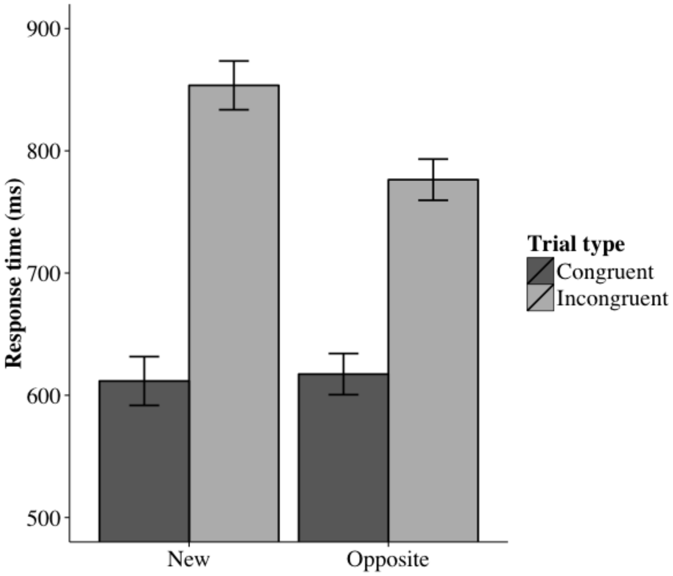

Figure 8. Mean response times (ms) for congruent and incongruent trials in the imagine-new and imagine-opposite conditions in Experiment 3. Error bars represent standard errors of the means corrected to remove between-subject variability (Cousineau, 2005; Morey, 2008).

The analysis revealed a significant main effect of trial type, $F(1, 31) = 56.49$, $p < .001$, $\eta^2_p = .64$. Responses were faster when the target color was congruent with the imagined color. The analysis also revealed a significant interaction between condition and trial type, $F(1, 31) = 8.69$, $p = .006$, $\eta^2_p = .21$. The RT difference between congruent and incongruent trial types was significantly greater in the imagine-new condition (242 ms) than in the imagine-opposite condition (159 ms; see Figure 8). This result is consistent with the idea that a PoP effect that speeds responses for target color repeats works in opposition to the imagery congruency effect for the imagine-opposite condition, whereas no such opposing influence exists in the imagine-new condition. Simple effects were also conducted separately for the two trials types, and revealed faster responses for the imagine-opposite than imagine-new condition for the incongruent trial type, $F(1, 31) = 6.21$, $p = .02$, $d = .21$, but no difference for the congruent trial type.

In a first analysis to assess the impact of the imagery probe ratings, we assessed broadly whether the probe ratings meaningfully impacted performance. Imagery probe ratings of ‘1’, ‘2’, and ‘3’ were collapsed together into an ‘other’ imagery category, while the imagery probe rating of ‘4’ constituted the ‘high’ imagery category. We categorized the probe ratings in this way given our a priori interest in assessing the influence of strong visual imagery, which we felt was captured best by ratings of ‘4’. It is also noteworthy that this method of dividing the data into high and other imagery categories resulted in imagery categories that had approximately equal numbers of observations, and led to the removal of the fewest participants from analyses. Mean RTs were then submitted to an ANOVA that treated trial type (congruent/incongruent) and probe rating (high/other) as within-subject variables, and that collapsed across the imagine-new and imagine-opposite conditions. The relevant mean RTs are displayed in Figure 9.

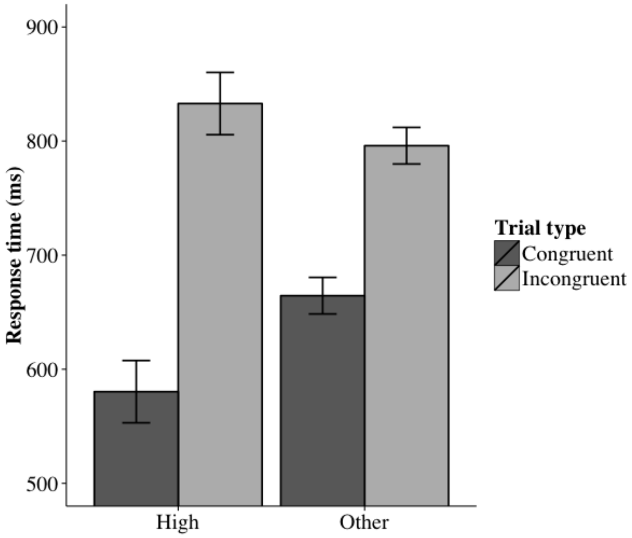

Figure 9. Mean response times (ms) for congruent and incongruent trials as a function of imagery vividness ratings in Experiment 3. Error bars represent standard errors of the means corrected to remove between-subject variability (Cousineau, 2005; Morey, 2008).

The analysis revealed a significant interaction between trial type and probe rating, $F(1, 23) = 7.18$, $p = .01$, $\eta^2_p = .18$. The difference in RTs between congruent and incongruent trial types was larger for high imagery probe trials (191 ms) than for other imagery probe trials (95 ms). This result is consistent with the view that the subjective estimates of the strength of visual imagery offered by participants on a trial-to-trial basis reflected the processes that underlie the measured congruency effect.[7]

In a second analysis to assess the impact of imagery, mean RTs were submitted to an ANOVA that treated trial type (congruent/incongruent), probe rating (high/other), and condition (imagine-new/imagine-opposite) as within-subject variables. Participants for whom there were empty cells were removed from the analysis, which in this case led to the removal of 14 of the 32

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[7] The correct RTs for the imagine-opposite condition were submitted to separate paired t-tests that assessed the impact of trial type (congruent/incongruent) from the second trial of one trial pair to the first trial of the following trial pair. There was a significant RT difference between switch (674 ms) and repeat (658 ms) trials, $t(31) = 2.10$, $p = .04$, $d = 0.03$, demonstrating that the reversal of the PoP effect occurred within trial pairs, whereas the usual PoP effect occurred across trial pairs.

participants from analysis. Although this is a large number of participants to be removed from analysis, we deemed it worthwhile to do this analysis for exploratory purposes. Mean RTs collapsed across participants are displayed in Figure 10.

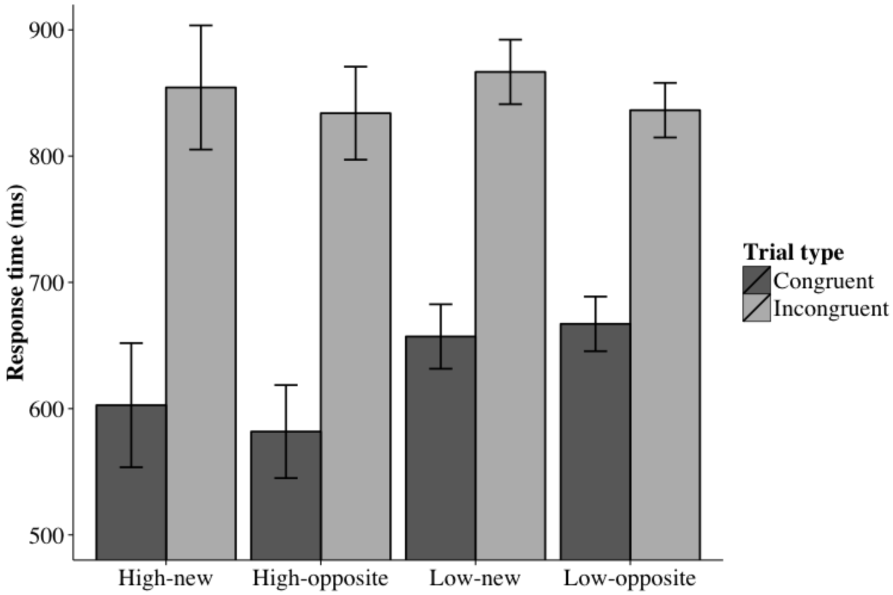

Figure 10. Mean response times (ms) for congruent and incongruent trials in the imagine-new and imagine-opposite conditions as a function of imagery vividness ratings in Experiment 3. Error bars represent standard errors of the means corrected to remove between-subject variability (Cousineau, 2005; Morey, 2008).

The analysis revealed a significant main effect of trial type $F(1, 17) = 31.74$, $p < .001$, $\eta^2_p = .50$, with faster responses for congruent than incongruent trials. Although no other effects in this analysis were significant, the results in Figure 10 reveal an interesting pattern. When looking only at the high probe rating trials (left side of Figure 10), the difference between congruent and incongruent trials appears to be near identical for the imagine-new condition (251 ms) and the imagine-opposite condition (252 ms). In contrast, when looking at the other probe rating trials (right side of Figure 10), the numerical trend is that observed in the overall analysis;

that is, the congruency effect is numerically larger for the imagine-new condition (210 ms) than for the imagine-opposite condition (169 ms).

Discussion

The primary purpose of Experiment 3 was to assess whether strategic expectancy that speeds performance for switches and an automatic process that speeds performance for repeats co-determine the reversal of the PoP effect reported in prior experiments reported here. To address this issue, we compared a condition in which the colors of target and distractors repeated across trials within trial pairs with a condition in which the colors of targets and distractors changed across trials within trial pairs. There were four main findings.

First, for both conditions, responses were faster when the imagined color was congruent with the target color than when it was incongruent. For the imagine-opposite group, this result constitutes a replication of the reversal of the usual PoP effect reported in Experiments 1A, 1B, and 2A, with faster responses for trials in which the target color switched from one trial to the next than when it repeated from one trial to the next. For the imagine-new group, the faster responses for congruent than incongruent trials highlights the strong influence of strategic expectancy (i.e., imagery) on performance in this search task.

Second, there was a significant interaction of condition and trial type, such that the RT difference between congruent and incongruent trial types was larger in the imagine-new condition than in the imagine-opposite condition. This result is consistent with the idea that an automatic visual memory process that speeds responses for repeats relative to switches does indeed contribute to performance in the imagine-opposite condition.

Third, we introduced imagery probes following each trial pair that asked participants to rate the strength of their imagery. In a first analysis using these probe ratings, we found that the trial type effect (i.e., congruent faster than incongruent) was larger for trials in the high imagery category (4 – strong imagery almost like perception) than for trials in the other imagery category (1 – no imagery, 2 – some imagery, 3 – moderate imagery, collapsed together). This result suggests that subjective reports of imagery given by participants on a trial-to-trial basis offer a useful measure of the strength of strategic use of imagery in this search task.

Fourth, we then used probe ratings to evaluate the interaction between condition and trial type described above. The objective of this analysis was to assess whether the influence of an automatic visual memory process that speeds performance for repeat trials would be present even when participants judge their visual imagery use to have been strong. If so, then the congruency effect ought to be larger for the imagine-new than the imagine-opposite condition even when participants claim to have engaged in strong visual imagery. In contrast, the congruency effect was almost identical for the imagine-opposite and imagine-new conditions when participants claimed to have generated strong visual imagery. Although this result must be interpreted with caution at this point until it is replicated and studied further, it points to the possibility that strong visual imagery impacts the same representations as drive the PoP effect.

General Discussion

The primary goal of the present study was to examine the influence of visual expectancy on the PoP effect, and in particular whether visual and verbal expectancies influence the PoP effect differently. In Experiments 1A and 2A, a control group given no expectancy instructions produced the typical PoP effect – faster response times for repeat than switch trials. These results demonstrate that the PoP effect is easily measurable and replicable using this procedure (see also Thomson et al., 2013). In contrast, participants in the visual imagery groups of Experiments 1A, 1B, and 2A, who were asked to imagine the ‘opposite’ color during the interval between trials in each trial pair, showed a reversal of the PoP effect – faster response times for switch than repeat trials. Although this result was not observed in Experiment 2B, pooled data across the visual imagery groups of Experiments 2A and 2B suggest that individual differences in visual imagery use mediates this effect; participants who reported engaging in the visual imagery strategy most often produced a significant reversal of the PoP effect. Moreover, participants in the verbal groups of Experiments 1B and 2B did not produce a reversal of the PoP effect. Taken together, the results across these experiments demonstrate that a visual imagery strategy can reverse the PoP effect, and that visual and verbal strategies impact the PoP effect differently (see also Maljkovic & Nakayama, 1994). To our knowledge, this is the first demonstration of a reversal of the usually robust PoP effect using visual imagery.

In Experiment 3, we examined the influence of visual imagery under conditions in which the color pairs of the target and distractor either remained the same as in earlier experiments (the imagine-opposite condition) or changed (the imagine-new condition) between trials in each trial pair. A key feature of the imagine-new condition was that the influence of congruency between visual imagery and search target color could be measured without any possible influence of the PoP effect pushing in the opposite direction. Indeed, the congruency effect differed between the imagine-opposite and imagine-new conditions, with the advantage for switch over repeat trials in the imagine-opposite condition being smaller than the advantage for congruent over incongruent trials in the imagine-new condition. This result suggests that the target color repetition effect for the imagine-opposite condition likely reflects a mix of two separate processes; a PoP effect that speeds performance for repeats relative to switches, and a visual imagery effect that speeds performance for switches relative to repeats.

One issue not addressed by the result described above is whether separate and opposing processes contribute to performance in the imagine-opposite condition on all trials. It seems possible that participants might not engage in visual imagery on all trials, in which case overall performance in the imagine-opposite condition could reflect a mix of performance for two distinct trial types, rather than a mix of two processes that occurred on all trials. To address this issue, we first confirmed that participants' subjective reports of imagery use on each trial predicted the magnitude of congruency effects on search performance. We then noted that, for trials in which participants reported strong visual imagery, the difference in size of the congruency effect for imagine-new and imagine-opposite conditions was negligible. In other words, we have preliminary evidence that separate and opposing processes contribute to performance in the imagine-opposite condition only when visual imagery is not subjectively strong. Although these preliminary results involving subjective reports of visual imagery must be interpreted cautiously at this point, they suggest that visual imagery may mediate the same visual representations as drive the PoP effect. According to such a view, these visual representations could impact ongoing visual experience because they can be altered passively by past experiences (Maljkovic & Nakayama, 1994), or more actively by strategic use of visual cues (Wolfe, Cave & Franzel, 1989; 1994) or visual imagery.

Process analysis of the PoP effect

The process that drives the PoP effect remains a debated issue (see Kristjansson & Campana 2010 for a review). Maljkovic and Nakayama (1994, 1996) proposed that the PoP effect is caused by a passive and automatic perseveration of short-lived visual memory representations that modulate target salience at a pre-attentive stage of processing (also see McPeek, Maljkovic & Nakayama, 1999; Goolsby & Suzuki, 2001; Becker, 2008a; Eimer, Kiss,

& Cheung, 2010; Kruijne, Brascamp, Kristjansson, & Meeter, 2015; Asgeirsson, Kristjansson, & Bundesen, 2015). Others have argued that the PoP effect reflects episodic retrieval and verification processes that perhaps occur at a later stage of processing (Hillstrom, 2000; Huang, Holcombe, & Pashler, 2004; Yashar & Lamy, 2010; Thomson & Milliken, 2011). It has also been argued that these two accounts are not mutually exclusive (Lamy, Yashar, & Ruderman, 2010; Tollner, Gramann, Muller, Kiss, & Eimer, 2008; Asgeirsson & Kristjansson, 2011); that is, PoP effects may be driven either by perseveration of visual memory representations that impact the salience of particular visual features, or by the retrieval of visual episodes (or events) that involve bindings between more than one visual (or response) feature. If both of these types of processes can contribute to PoP effects, then it is worth discussing which of these two processes was likely impacted by our visual imagery manipulation.

Although further research is required to settle this issue, we propose that visual imagery impacted the PoP effects reported here by mediating visual saliency of target/distractor color features. Our rationale for this proposal is two-fold. First, participants were instructed to imagine a colored square, rather than a colored object that matched precisely the shapes in the search array. Specifically, the search array stimuli were square-like Landolt C's rather than full squares. Given this representational dissimilarity, it seems unlikely that specific matches that involved shape-color bindings were responsible for the visual imagery congruency effects. Rather, it seems more likely that feature (color) representation matches between visual imagery and perception were responsible for the congruency effects. Second, many of the participants (as well as the corresponding author of this manuscript) reported that their attention was immediately drawn to the color stimulus that matched the imagined color. This strong subjective experience of attention shifting fits with the idea that it was automatic attention shifting driven by color salience that produced fast responses to switch trials, and slow responses to repeat trials.

Supplementary evidence for this interpretation comes from research showing that representations held in working memory impact pop-out search. For example, Olivers, Meijer, and Theeuwes (2006) found that visual search times were slowed by a singleton distractor that matched a representation held in working memory. Similarly, Soto, Humphreys, and Heinke (2006) found that representations held in working memory led to fast responses when they matched the target and slow responses when they matched a distractor. Further, this effect was driven by short first saccade latencies suggesting that representations held in working memory captured attention at a pre-attentive stage of processing. We propose that imagined representations of color had a similar impact on performance; colors generated by visual imagery caused matching colors in the search display to be captured by attention. In this sense, our findings support the notion that the PoP effect can be mediated by representations held in working memory.

If visual imagery impacts the same representations as drive the PoP effect, and if visual imagery generated a representation that effectively replaced that of the prior target color, then the control and imagery groups ought to have produced results that mirror each other. To some extent, this prediction fits the data well. For example, Figure 2 illustrates that response times for repeat trials in the control group were similar to those for switch trials in the imagery group. However, response times for repeat trials in the imagery group were substantially higher than those for switch trials in the control group in several experiments. This unexplained aspect of the results observed here deserves some comment. To explain this pattern of results, we note that the PoP effect in tasks like that used in our study may be jointly determined by two separate influences: a performance benefit when the target and distractors are repeated across trials and a cost when the target and distractors switch across trials (Eimer, Kiss, & Cheung, 2010; Rorden, Kristjansson, Revill, & Saevarsson, 2011). The performance cost for switch trials may be due to incidental attentional orienting to the distractors (Becker, 2008b) that follows from use of the previous target representation to disambiguate a current target from distractors (Meeter & Olivers, 2006; Hickey, Olivers, Meeter, & Theeuwes, 2011). By this view, when the target and distractor colors switch across trials, the retained target representation from the prior trial matches the distractor representation of the current trial, which in turn causes the observer to inappropriately orient their attention to distractors. Furthermore, to the extent that attention is drawn to a distractor rather than the target, disengagement of attention from the distractor and re-engagement of attention on the target may be necessary. This correction in the orienting of attention typically slows responses for switch trials, but of course in the imagery groups of our experiments it would have slowed responses for repeat trials when an imagined color matched the distractors rather than the target.

To explain why this performance slowing might have been more profound for repeat trials in the imagery groups than for switch trials in the control groups we assume that it depends on the strength of the color representation held in memory. Note that the color representation held in memory for participants in the imagery group may have been maintained in memory up until the point at which the following visual search display appeared. In contrast, the prior target representation in memory for the control group may have decayed passively over the two-second inter-trial interval (Thomson & Milliken, 2013; Brascamp, Pels, & Kristjansson, 2011; Martini, 2010), as there was no requirement to retain that representation over the inter-trial interval. Thus, holding a color representation in an active state across the inter-trial interval in the imagery groups may have increased the cost associated with disengaging attention following an erroneous shift of attention to a distractor (see Olivers, Peters, Houtkamp, & Roelfsema, 2011). Indeed, participants reported that it was particularly disorienting when the target color did not match the imagined color. Future research could benefit from a more thorough investigation of this topic.

Verbal expectancies and visual search

The limited impact of verbalization on the PoP effect in the present study may be related to results that have compared verbal and visual cues in studies of visual search. As noted in the Introduction, verbal cues indicating the identity of a target (Wolfe et al., 2004), or the singleton dimension of a target (Theeuwes et al., 2006), tend to be less effective in guiding visual search than are visual cues that exactly replicate the target. Note that we are not implying that verbal representations cannot impact performance in perceptual tasks at all, nor that verbal expectancies in the present study had no impact on the PoP effect. In fact, some participants in the verbal groups of Experiments 1B and 2B did produce faster responses to switch trials than repeat trials, and the null PoP effect for the verbal group in Experiment 1B suggests that verbal expectancies did produce an effect that opposed the usual PoP effect. Rather, the results here and elsewhere suggest that verbal cues may elicit categorical representations that lack visual specificity in at least some individuals on some occasions.

The idea that verbal cues can, in some cases, elicit expectations that have a visual representational basis suggests that effective instructions to participants, and perhaps incentives to engage visual mechanisms in response to verbal cues, may be critical to measure such effects. This observation fits with an interesting result reported by Muller and Krummenacher (2006). In contrast to the null verbal cue validity effect on singleton search reported by Theeuwes et al. (2006), they reported that verbal cue validity impacted singleton search performance when participants were incentivized to use the verbal cues. Interestingly, Tollner, Zehetleitner, Gramann, and Muller (2010) explored this topic further and showed that this cue validity effect appears to affect an early stage of visual processing. Although anecdotal in nature, it is also interesting to note that several participants in the verbal groups of our study who did produce a reversal of the PoP effect reported in a post-experiment questionnaire that colour imagery was automatically evoked when they said a colour aloud. It would be interesting to examine in further research whether individual differences in the tendency for verbal expectancies to evoke visual imagery can account for variability in the PoP effect. Additional questions worth pursuing are whether verbal expectancies can be disengaged from more quickly than visual expectancies, and whether verbal cues can produce expectations that have a visual representational basis if participants are given sufficient time following the verbal cue to construct a visual expectancy (see Huettig, & McQueen, 2007; Wolfe et al., 2004).

Imagery effects in other visual tasks

Our results may be related to those in several other studies that have demonstrated the efficacy of visual imagery in cognitive tasks. For example, Chang et al. (2013; see also Pearson, et al., 2008) showed that mental images of colour can impact performance in a binocular rivalry task. In particular, Chang et al. found that when participants were cued to imagine a colour prior to a binocular rivalry task, their perception in the binocular rivalry task was biased in favor of the colour they were imagining. Similarly, Wantz et al. (2015) cued participants to imagine a colour prior to each trial of a colour identification task. They showed that participants were faster to identify target colours that were congruent than target colors that were incongruent with the color they were imagining.

One straightforward explanation for why imagined colours and perceptual colours interact in this way is that there is a degree of overlap in the internal representations of colors that are imagined and colors that are perceived (Howard et al., 1998; also see Kosslyn, Ganis, & Thompson, 2001). From this standpoint, if one wants to demonstrate an expectancy effect on visual search, the expectancy ought to involve visual imagery – such expectancies are likely to involve representations that overlap with those that drive performance in the visual search task. In contrast, verbal expectancies may involve representations that overlap less with those that drive performance in visual search. This idea is supported by the results of Experiment 3. When participants reported strong visual imagery, there was no residual influence from the preceding target color on performance, which fits with the view that visual imagery and preceding target color affect overlapping rather than separate processes.

Conclusion

The results reported here demonstrate that expectancies that involve visual imagery can affect the PoP effect profoundly, reversing it so that performance is faster for switch than repeat trials. The results also suggest that expectancies involving verbalization influence the PoP effect less profoundly. A straightforward explanation for these findings is that expectancies may influence visual search to the extent that the expectancies involve representations that overlap with those critical for performing the visual search task.

Chapter 3: Cueing color imagery: a critical analysis of imagery-perception congruency effects

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Preface

Chapter 3 presents the results of 9 experiments that evaluated whether color imagery facilitated the processing of perceptually colored objects as reported by Wantz, Borst, Mast, and Lobmaier (2015). In Experiment 1, we replicated the basic effect reported by Wantz et al. showing that participants were faster to identify colors that were proceeded by congruent color imagery than incongruent. In Experiment 2, we used the same procedure except that now there were only two possible colors, which controlled for issues with the probability of the matching trials present in Wantz et al., which revealed that the effect was substantially reduced. In Experiment 3 we further controlled for response biases by having participants perform a notch detection task instead of a color identity task, which eliminated the effect. In the remaining experiments we evaluated whether color imagery could lead to efficient allocation of matching targets in space. In Experiments 4a and 4b, we found that varying the target location did not produce any effects. However, by including distractors in the stimulus array, we observed in Experiments 5a, 5b, 6a, and 6b that color imagery facilitated performance.

Abstract

The relation between mental imagery and visual perception is a long debated topic in experimental psychology. In a recent study, Wantz, Borst, Mast, and Lobmaier (2015) demonstrated that color imagery could benefit color perception in a task that involved generating imagery in response to a cue prior to a forced-choice color discrimination task. Here, we scrutinized whether the method of Wantz et al. warrants strong inferences about the role of color imagery in color perception. In Experiments 1-3, we demonstrate that the imagery effect reported by Wantz et al. does replicate nicely using their method but does not occur when cue-target contingencies and a redundancy between the imagery and response dimensions are removed from their method. In Experiments 4-6, we explored cued imagery effects further using a method in which the cued imagery dimension was orthogonal to the response dimension. The results of these experiments demonstrate that a compelling endogenously cued imagery effect does not occur for lone targets but does occur for singleton color targets embedded amidst homogenous color distractors.

Introduction

Imagine a ripe tomato. You may see in your mind's eye the vibrant red coating of a fresh tomato attached to a green vine. Presuming you had such an experience, it may seem self-evident that mental imagery can be much like seeing objects in the real world (Kosslyn, 1994). However, the relation between visual perception and mental imagery has long been a controversial topic in the literature, with some researchers arguing that imagery is fundamentally non-visual (Pylyshyn, 2003). This issue has been difficult to study in a scientifically rigorous way, given the methodological limitations in exploring a topic so deeply rooted in subjective experience.

Recently, Wantz, Borst, Mast, and Lobmaier (2015) developed a new method to explore this issue. They asked participants to imagine a color on each trial, and then measured forced-choice identification performance for a following target color. Color identification for the target color was indeed faster when it matched than when it mismatched the imagined color. Further, this imagery effect mirrored the effect found under comparable conditions in which an actual perceptual color patch was presented prior to a target color. Based on these findings, Wantz et al. concluded that mental imagery representations are functionally similar to visual representations.

One aim of the present article is to offer a critical analysis of the method used by Wantz et al. (2015) – we argue that the method used by Wantz et al. does not allow strong inferences about functional similarity of representations underlying mental imagery and visual perception. At the same time, the broad objective embodied by the Wantz et al. study is an important one; to examine whether endogenously cued mental imagery relies on representations that also support performance in perceptual tasks. Therefore, a second aim of the present study is to describe how the method used by Wantz et al. can be adapted to offer more conclusive evidence of the influence of color imagery on color perception. A brief review of the relevant mental imagery literature follows, prior to a more detailed discussion of the Wantz et al. study, and an introduction to the series of experiments reported in the present study.

The relation between imagery and perception

There is a longstanding debate in the literature about the relation between images generated endogenously in the mind's eye and visual representations that depict objects and events we experience in the real world (Tye, 1991). Early studies supporting the notion that mental imagery and visual perception share representational systems explored mental image rotation and scanning (Kosslyn, 1973; Shepard & Metzler, 1971; Shepard & Cooper, 1982). In one such experiment, two three-dimensional shapes were displayed and participants had to identify whether the two shapes were the same shape portrayed in different orientations or different shapes (Shepard & Metzler, 1971). When the two shapes were the same, response times were shown to vary with the orientation difference between them; that is, response time increased linearly with the degree of orientation difference between the two shapes. Shepard and Metzler interpreted this finding as evidence that participants were mentally rotating the shapes, much like is possible with physical objects in the real world.

One of the problems with interpreting findings like those described above as evidence of mental imagery is that they can often be explained by alternative accounts that appear more parsimonious. For example, when participants are instructed to imagine an object they might well engage representations that share some of the constraints of visual representations, but that fall short of genuinely constructing mental images that are isomorphic with visual representations. In the case of mental rotation studies, the dependence of response time on the angular difference in orientation of two objects is consistent with the idea that one rotates a mental image in the mind's eye but does not require this interpretation. Pylyshyn (1979; 2003) has argued that it is presumptuous to assume the existence of perception-like mental representations when these types of problems can be resolved in a propositional manner. Dennett (1969) further demonstrates the limitations of mental imagery with a thought problem; first imagine a tiger, and then count its stripes. People commonly report that the mental representation of the tiger distorts as attention orients to each stripe. This example not only challenges the notion that mental imagery is like visual perception, but also highlights a critical problem with early research on imagery: arguments for and against imagery being perception-like were based on a blend of debatable empirical results and introspection.

More recent studies have explored mental imagery ability following brain injury. In one such study, a participant with damage to anterior inferior occipital regions with an intact primary visual cortex performed both perceptual and imagery color discrimination tasks (Bartolomeo, Bachoud-Levi, & Denes, 1997). In the perceptual color discrimination task, the participant was required to arrange a series of color patches in a rainbow-like configuration. In the color imagery task, the participant was required to indicate the color of specific objects presented to them verbally. Performance was poor in the perceptual color discrimination task, while performance was unimpaired in the imagery task. Based on the details of responses to the imagery task, researchers concluded that the participant was relying on imagined representations to perform the imagery task, as opposed to non-visual knowledge-based representations of the objects (for similar results see also Chatterjee & Southwood, 1995; Goldenberg, Mullbacher, & Nowak, 1995; Shuren, Brott, Scheft, & Houston, 1996; Zago et al., 2010). In a similar study, Goldenberg (1992) showed that a patient with temporo-occipital damage had difficulty indicating the color of an object in an imagery task similar to that described above but showed unimpaired perceptual color discrimination. Together, these results suggest that color mental imagery and colour perception may depend on separate mechanisms.

However, recent neuroimaging studies have been less conclusive. Contrary to the double dissociation between color imagery and perception described above, many studies have shown an overlap in activated brain regions during color imagery and perception (Ishai et al., 1999; O'Craven & Kanwisher, 2000; Slotnick, Thomson, & Kosslyn, 2005; for a review, see Kosslyn & Thomson, 2006). Specific to color, some studies have shown that brain regions early in the visual processing stream, such as V4, are active during mental imagery, supporting the notion that imagery and perception have similar representational bases (Hsu, Frankland, & Thompson-Schill, 2012; Rich et al., 2006; Simmons et al., 2007; Thomson & Kosslyn, 2005). On the other hand, other studies have shown that imagery does not depend on activity in these early visual processing areas (Bramao, Faisca, Reis, & Peterson, 2010; Chao & Martin, 1999; Howard et al., 1998; Lu et al., 2010). Kosslyn and Thomson (2003) note that the discrepancy between results is not so much a matter of unreplicability, but rather is related to subtle differences in experimental method between the studies. In their meta-analysis they showed that even seemingly arbitrary method details, such as whether the imagery task was conducted in the presence of ambient light, had an impact on the imagery results.

A number of new behavioural methods have also been used recently to address the mental imagery debate. The general rationale in these methods is that if effects typically caused by perceptual stimuli are also observed when imagined stimuli are used in their place, then such effects provide evidence that imagery and perception engage similar processes. For example, perception and imagery have been shown to produce similar effects in binocular rivalry tasks. In a typical binocular rivalry task different stimuli are presented to each eye such that the two stimuli overlap in the visual field, and participants are asked to indicate which of the two stimuli are visible. Chang, Lewis, and Pearson (2013; Pearson, Clifford, & Tong, 2008) found that when participants were cued with a perceptual color, there was a visibility bias for that color in a subsequent binocular rivalry task. Similarly, when participants were required to imagine a color prior to a binocular rivalry task, participants' perception in the binocular rivalry task was biased towards the imagined color. In a further study, the strength of this color imagery bias in binocular rivalry corresponded with trial-by-trial subjective estimates of imagery quality (Pearson, Rademaker, & Tong, 2011).

Another behavioural domain in which imagery effects have been observed is visual search. In one study, it was found that when participants imagined performing a visual search task prior to performing an actual visual search task, there was a benefit akin to that observed with actual visual search practice (Reinhart, McClenahan, & Woodman, 2015; though see Clarke, Barr, & Hunt, 2016). In another study, it was found that imagery can override a robust intertrial priming effect known as Priming of Pop-out (PoP; Cochrane, Nwabuike, Thomson, & Milliken, 2018; Cochrane, Zhu, & Milliken, under revision). The PoP effect is found in singleton search tasks and consists of faster responding when the target and distractor features remain the same across trials relative to when they switch across trials (Bravo & Nakayama, 1992; Maljkovic & Nakayama, 1994). Cochrane et al. set in opposition the PoP effect and color imagery by asking participants to imagine the color opposite to the previous target between trial pairs of a visual search task. Under these conditions, the typical PoP effect was reversed, with faster responses to targets that matched the imagined color rather than the previous target color.

This result demonstrates that imagery can guide attention towards congruent color targets (see also Moriya, 2018).

Mental imagery and priming of color identification: Wantz et al. (2015)

In a recent study, Wantz et al. (2015) reported a series of experiments that demonstrated a form of priming of perceptual color identification by color imagery. Participants were shown the first two letters of a color and instructed to imagine that color in a blank box that was presented centrally on screen. After the imagery period, a color was displayed in that box and participants were required to identify that color by pressing a corresponding response key. Responses were faster on trials in which the visualized color matched the presented color (congruent trials) than on trials in which the visualized color did not match the presented color (incongruent trials). This result suggests that endogenously generating a color in the mind's eye can prime the identification of perceptual colors. In Experiment 2, a similar finding was observed when participants were required to perform an articulatory suppression task at the same time as the color imagery task, suggesting that the imagery effect was due to activation of visual rather than verbal representations. Lastly, they showed that presentation of a perceptual color cue prior to the color identification task yielded similar results to those in the imagery condition, suggesting the presence of functional overlap in the processes involved in perception and imagery.

The findings of the Wantz et al. (2015) study constitute an important extension of the influence of imagery on perception with a compellingly simple identification task. However, we noted that there were some features of their method that limit the strength of inference that can be made regarding the role of mental imagery in their results. First, participants completed a six-alternative forced choice color discrimination task for the target square by pressing one of six different response keys. Within each experimental trial however, the likelihood that the cue would be congruent with the target was .50. In other words, the correct response was the key corresponding to the cue on 50% of trials, whereas the correct response was each of the other five keys on 10% of trials. This strong contingency favoring the response associated with the cue might well produce an effect quite apart from any putative mental imagery generated in response to the cue. Second, participants in the Wantz et al. study performed an identification task in which the response dimension (i.e., color) was identical to the dimension on which participants were asked to generate mental imagery. As a result, even if the response contingency issue described above were addressed, it would remain unclear whether faster responses to congruent than incongruent trials owed to activation of response representations or activation of visual representations in response to the cue.

The present study

To address these two critical issues, we report a series of six experiments. In the first three experiments, we demonstrate that when cue-target contingencies are reduced to chance likelihood, and when stimulus and response dimensions are made orthogonal to each other, the imagery effect reported by Wantz et al. (2015) is not observed. We conclude that the method introduced by Wantz et al. does not allow one to make strong inferences about the role of color imagery in color perception and identification. In the final three experiments, we adapt the method of Wantz et al. in ways that allow us to make a much stronger claim about the role of color imagery on color perception. Specifically, using a method in which the response dimension is orthogonal to the imagined color dimension, we find strong effects of color imagery on search for a singleton color target among distractors. We believe the results here support a more nuanced view of imagery than proposed by Wantz et al. On the one hand, our results do not support the specific claim that endogenously generated color imagery can speed subsequent color identification. On the other hand, our results do support the broader view that endogenously generated color imagery can impact color perception – the correspondence between color imagery and color perception clearly impacts attention in visual search contexts.

Experiment 1

The purpose of this first experiment was simply to replicate the basic finding of the Wantz et al. (2015) study. Participants were asked to imagine a color in response to a two-letter cue prior to completing a color discrimination task on a following target. In the Wantz et al. study, responses were substantially faster for targets that matched the imagined color than for targets that mismatched the imagined color. The same number of trials and participants were used here and in the Wantz et al. study to ensure that statistical power was comparable across the studies.

Method

Participants. Sixteen undergraduates at McMaster University (13 female, M_{age} = 18.4 years) took part in exchange for course credit. All participants had normal or corrected-to-normal vision.

Apparatus and stimuli. Stimuli were presented using Psychopy v1.84 on a BenQ 24-inch LED monitor that was connected to a mac mini computer. All displays were presented on a black background. Cues were the first two letters of the color that was to be imagined presented in 18-pt white Times New Roman font (e.g., ‘gr’ was used as a cue to imagine the color green). Target squares were centrally located and one of six different colors (red, yellow, orange, green, blue, purple). Blank squares were centrally located and displayed in white outline on a black background. All squares subtended horizontal and vertical visual angles of 10.7 degrees.

Procedure. Participants were seated approximately 60 cm from the computer screen. Each trial began with a blank display that lasted 500 ms, followed by a centrally located fixation cross for 500 ms. A two-letter cue was then presented in the center of the screen for 500 ms, indicating which particular color was to be imagined. A blank display was then presented for 500 ms, followed by a blank square that remained on the screen for 2000 ms. Prior to the experiment, participants were instructed to imagine that the blank square was the color indicated by the cue presented earlier in the trial sequence. The target square was presented immediately following the 2000 ms blank square, and participants were instructed to indicate its color. Each color was assigned to a key: ‘x’ = yellow, ‘c’ = orange, ‘v’ = red, ‘b’ = green, ‘n’ = blue, ‘m’ = purple. Participants responded using the ring, middle and index fingers of their left hand for yellow, orange, and red, respectively, and the index, middle, and ring fingers of their right hand for green, blue, and purple, respectively.

Prior to the experimental session, to ensure that participants understood the mapping of colors to response keys, participants were shown each color in turn and were instructed to respond by pressing the corresponding response key. Following this practice phase, participants completed two blocks of 100 trials each. Within each block, cues were randomized on a trial-by-trial basis such that each cue was equally likely. The target color matched the cue on half the trials (congruent trials) and mismatched the cue on half the trials (incongruent trials). For incongruent trials, the target color was chosen randomly from the remaining five colors (those that mismatched the cue), implying that each of these five colors had a .10 likelihood of being chosen as the target color. The two blocks were separated by a short break that participants could end by key press when ready to continue. Following the experimental session, participants completed a paper-based Vividness of Visual Imagery Questionnaire (VVIQ; Marks, 1973). An example of the trial sequence is presented in Figure 1.

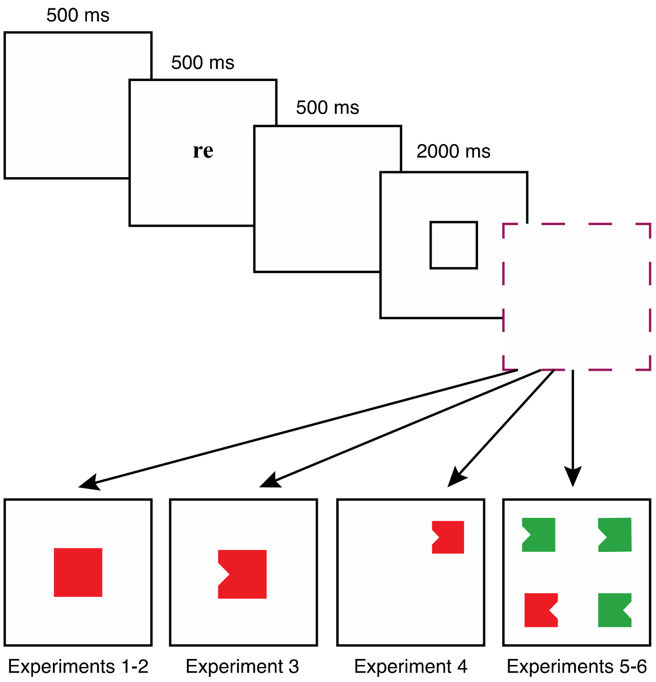

Figure 1. This figure depicts a typical trial sequence across experiments. Across all experiments the trial sequence was identical with the exception of the target display. In Experiment 1, participants were required to identify one of six colors by selecting the corresponding key. In Experiment 2, participants performed the same task except that there were only two possible colors. In Experiment 3, participants indicated the side of the gap of the colored square. In Experiments 4a and 4b, participants indicated the side of the gap of the colored square when the target's location was uncertain. In Experiments 5a and 5b, participants indicated the side of the gap of the oddball colored target. Experiments 6a and 6b were identical to the previous experiment with the exception that participants performed an articulatory suppression task during the presentation of the empty box.

Results

Response times (RTs) that were less than 200 ms or greater than 2000 ms were first excluded from analysis (3.1% of RTs excluded). The remaining correct RTs were submitted to the non-recursive outlier elimination procedure of Van Selst and Jolicoeur (1994), which ensures that different proportions of observations are not systematically excluded from cells with different numbers of observations. This outlier procedure led to the removal of 2.9% of correct

RTs.[8] Mean RTs were computed from the remaining observations, and these mean RTs and corresponding error rates were submitted to a one-way within-subject ANOVA that treated cue type (congruent/incongruent) as a factor. Mean RTs are presented in Figure 2 and error rates are presented in Table 1. An alpha criterion of .05 was used to determine statistical significance in all analyses reported in this article.

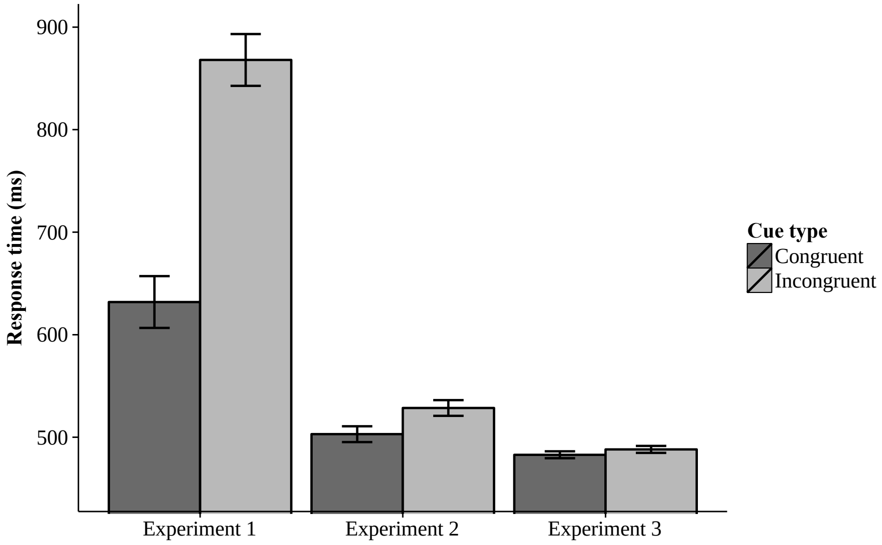

Figure 2. Mean response times for congruent and incongruent cue types for Experiments 1-3. Error bars represent the standard error of the mean corrected for between-subject variability (Cousineau, 2005; Morey, 2008).

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[8] For all experiments, identical within-subject analyses were conducted using correct median RTs as the primary dependent variable without any additional outlier removal procedures. These analyses produced results that had the same outcome as those reported throughout the manuscript, with the exception that the effect of cue type that approached significance in Experiment 6a (p = .08) was clearly nonsignificant when median RTs were analyzed (p = .27).

Table 1. Mean error percentages (%) across experiments.

	Cue type	
Experiment	Congruent	Incongruent
1	1.8	4.3
2	2.4	3.7
3	3.1	3.0
4a	3.0	2.5
4b	2.7	2.8
5a	1.7	5.7
5b	3.0	4.4
6a	5.3	6.9
6b	6.0	6.3

The analysis of RTs revealed a significant effect of cue type, $F(1,15) = 43.7$, $p < .001$, $d = 1.36$, with faster responses for congruent trials (632 ms) than for incongruent trials (868 ms). The analysis of error rates revealed an effect of cue type that approached significance, $F(1,15) = 4.3$, $p = .055$, $d = .72$. In line with the pattern of RTs, the error rate was higher for incongruent trials than for congruent trials.

We were also interested in whether the imagery effects (incongruent - congruent RTs) correlated with VVIQ scores. To address this issue, we first confirmed that the congruency effect itself was reliable. Separate imagery effects were computed for the two experimental blocks, and the high correlation between these two measures indicated that the imagery effect was indeed reliable, $r(14) = .87$, $p < .001$. However, the correlation between imagery effects and VVIQ scores was not significant, $r(14) = .19$, p = .47.

Discussion

The purpose of this experiment was to replicate Experiment 1 of Wantz et al. (2015). In the present study, responses were 236 ms faster when the imagined color was congruent with the target color than when it was incongruent with the target color. Wantz et al. (2015) reported an effect of approximately 170 ms. Clearly, our procedure produced a similar result to that reported by Wantz et al.

Experiment 2

In Experiment 1 of the present study, and in the experiments reported by Wantz et al. (2015), the imagery cue was congruent with the color of the target on half of the trials, and incongruent on the other half of trials. Importantly, on congruent trials the correct response was always the response key corresponding to the cued color, whereas on incongruent trials the correct response was one of the other five keys. With this design the cue offered predictive information about the identity of the following target, with the target being five times more likely to be the color indicated by the cue than any of the other five colors. Consequently, preparation to press the response key associated with the cued color could have contributed to the imagery effect, simply because it was a more probable correct response than any of the other five colors.

To address this issue, we adapted the method of Wantz et al. (2015) to use two colors rather than six colors. With each of two colors mapped to one of two responses there was no longer a predictive relation between the cue and target. If the imagery effects in the Wantz et al. study and in Experiment 1 were influenced by cue-target contingencies that encouraged response preparation, then the imagery effect ought to be smaller in the present two-color variant of the method than in the six-color variant used in Experiment 1.

Method

Participants. Sixteen undergraduates at McMaster University (12 female, M_{age} = 18.5 years) took part in exchange for course credit. All participants had normal or corrected-to-normal vision.

Apparatus and stimuli. The apparatus and stimuli were identical to those used in Experiment 1 with the exception that now only two colors (red and green) were used.

Procedure. The procedure for Experiment 2 was identical to Experiment 1 with the exception that there were now only two response keys corresponding to the two colors. As in Experiment 1, half of the trials were congruent and half incongruent, which in this case meant that the cue did not offer predictive information about the upcoming target. Response key mappings were counterbalanced across participants: half of participants responded to red targets by pressing ‘m’ with the index finger of their right hand, and to green targets by pressing ‘z’ with the index finger of their left hand, while the other half of participants had the opposite response key mapping.

Results

RTs less than 200 ms or greater than 2000 ms were first excluded from analysis (0.3% of RTs excluded). The remaining correct RTs were submitted to the same outlier procedure used in Experiment 1 (2.6% of RTs excluded). Mean RTs were computed from the remaining observations, and these mean RTs and corresponding error rates were submitted to one-way within-subject ANOVAs that treated cue type (congruent/incongruent) as a factor. Mean RTs are displayed in Figure 2, and error rates are displayed in Table 1.

The analysis of RTs revealed a significant effect of cue type, $F(1,15) = 5.5$, $p = .03$, $d = 0.20$, with faster responses for congruent trials (503 ms) than for incongruent trials (529 ms). Error rates for the two cue types did not differ significantly ($p = .18$).

Again, we were interested in whether the imagery effect correlated significantly with participants’ VVIQ score. Reliability of the imagery effect across blocks was again quite good,

$r(14) = .81$ $p < .001$, whereas the correlation between imagery effects and VVIQ scores was again not significant $r(14) = -.10$, $p = .71$.

Discussion

With the two-color variant of the Wantz et al. (2015) method, the imagery effect was reduced from 236 ms in Experiment 1 to 26 ms in Experiment 2. This result is consistent with the view that predictive information offered by the cue about the following target contributed to the imagery effect in the Wantz et al. study and in Experiment 1 of this study. This predictive information from the cue could have been used in several ways to speed responses to congruent trials relative to incongruent trials. One possibility is that the predictability of the target from the cue incentivized use of mental imagery to facilitate response to the following target. It is important to note that we cannot rule out this account of the difference between Experiments 1 and 2. However, the more important point is that there is a salient alternative account of these results that is not addressed in the Wantz et al. study. Specifically, participants may have used the predictive cues to pre-activate a response that matched the color of the target on half of the trials. In our view, the fact that the imagery effect reported by Wantz et al. is open to this second interpretation makes their method less than ideal to demonstrate the influence of mental imagery on visual perception.

Experiment 3

Although a cue-target contingency may encourage response pre-activation prior to onset of the target, even without such a contingency the method of Experiment 2 is still open to this interpretation. In principle, participants could have prepared a response that matched the color cue prior to onset of the target, rather than (or in addition to) imagery that matched the color cue. As such, even the method used in Experiment 2 is not ideal to make inferences about the influence of color imagery on color perception. To address this issue in Experiment 3, we orthogonalized the imagery and response dimensions of the color identification task. The stimuli were similar to those used in Experiments 1 and 2, but a "notch" was removed from either the left or right side of the target square. Participants were now instructed to indicate the side of the target square (left or right) that was missing a notch. If a significant imagery effect were to occur in this experiment, it could not be explained by response activation triggered by the cue – the cue triggered imagery of a particular color whereas the correct response was either 'left' or 'right'. In this sense, orthogonalizing the imagery and response dimensions in this task constitutes a method that could, in principle, produce a more compelling demonstration that visual representations (rather than response representations) activated in support of mental imagery can influence the efficiency of performance in a visual perception task.

Method

Participants. Sixteen undergraduates at McMaster University (15 female, M_{age} = 18.6 years) took part in exchange for course credit. All participants had normal or corrected-to-normal vision.

Apparatus and stimuli. The apparatus and stimuli were identical to those used in Experiment 2 with the exception that now the target squares had a missing V-shaped notch on either the left or the right side.

Procedure. The procedure was the same as Experiment 2 in many respects. Again, participants imagined that the blank square was the color indicated by the cue (red or green). However, participants were now instructed to indicate the side of the target square that was missing the notch. The notch location was randomly on either the right or left side of the target. Participants indicated that the notch was on the right side of the target by pressing the 'm' key with the index finger of their right hand, or that it was on the left side of the target by pressing the 'z' key with the index finger of their left hand.

Results

RTs less than 200 ms or greater than 2000 ms were excluded from analysis (0.1% of RTs excluded). The remaining correct RTs were submitted to the same outlier procedure as in prior experiments (2.4% of RTs excluded). Mean RTs were computed from the remaining observations, and these mean RTs and corresponding error rates were submitted to one-way within-subject ANOVAs that treated cue type (congruent/incongruent) as a factor. Mean RTs are displayed in Figure 2, and error rates are displayed in Table 1.

The analysis of RTs revealed a non-significant effect of cue type, $F(1,15) = 1.2$, $p = .29$, $d = .07$ (congruent = 483 ms, incongruent = 488 ms). Error rates for the two cue types also did not differ significantly ($p = .85$).

Discussion

In this experiment, the mental imagery dimension (color) was set to be orthogonal to the response dimension (left/right). The imagery effect was not statistically significant with this method. Together, the results of Experiments 2 and 3 demonstrate an imagery effect that occurs when imagery and response dimensions are identical (i.e., color) but not when imagery and response dimensions are orthogonal (i.e., color and left/right). In turn, we might conclude that the imagery effect observed in Experiments 1 and 2 is indeed driven by response activation rather mental imagery that involves visual representations.

At the same time, there are alternative interpretations of the results of Experiments 1-3. For example, the task in Experiment 3 directed participants' attention to the side of the target square with a missing notch rather than to the color of the target square. It may be that color imagery only influences performance in tasks in which the processing of color plays a key role. If so, then the absence of an imagery effect in Experiment 3 might occur even if endogenously cued color imagery does affect visual representations that support color perception – the left/right discrimination simply may not depend at all on visual representations activated by color imagery.

The broader point is that the purpose of orthogonalizing the imagery and response dimensions in Experiment 3 was to rule out response activation as the cause of the imagery effect reported by Wantz et al. (2015) and in Experiments 1 and 2 of the present study. The absence of an imagery effect in Experiment 3 constitutes a failure to rule out response activation as the cause of these effects, but it does not rule out the possibility of finding an imagery effect for which response activation can be ruled out as a cause. As such, in the following experiments we adapted our method with an aim to: (1) produce a strong endogenously cued imagery effect; and (2) rule out response activation as a cause of this effect.

Experiments 4a and 4b

We have suggested that imagery effects of the type measured in this study may depend on the degree to which visual representations that support mental imagery impact processing for the task at hand. In the context of a task that requires only the identification of which side of an object is missing a notch, it may be that mental imagery for the color of that object plays no useful role. In contrast, if the task involves other component processes that benefit from activation of visual representations associated with color, then mental imagery of target color might well play a useful role.

One candidate set of processes that may be affected by activation of visual representations in support of mental imagery are those involved in target localization, or more generally visual search. In studies of visual search, it has been demonstrated that setting up a mental representation that acts as a target template aids performance (Cochrane, Nwabuike, Thomson, & Milliken, 2018; Moriya, 2018; Vickery, King, & Jiang, 2005; Wolfe, Butcher, Lee, & Hyle, 2003; Wolfe et al., 2004). If formation of a target template facilitates search for a target, then adding a target localization component to the task used in Experiment 3 may well produce an imagery effect. In Experiments 4a and 4b, we took a first step toward addressing this issue. Specifically, location uncertainty of the target square was introduced by placing it randomly in one of four locations equidistant from the center of the screen. With the introduction of location uncertainty, our hypothesis was that mental imagery of the target color now might be used to help localize the target prior to identifying the side of the target object that was missing a notch.

Methods

Participants. Thirty-two undergraduates at McMaster University took part in Experiments 4a (16 participants; 12 female, M_{age} = 18.5 years) and 4b (16 participants; 13 female, M_{age} = 19.1 years) in exchange for course credit. All participants had normal or corrected-to-normal vision.

Apparatus & Stimuli. The apparatus was identical to previous experiments. The stimuli in this experiment were similar but smaller, with the target and the blank squares now subtending approximate horizontal and vertical visual angles of 2 degrees each. In addition, there were four possible target locations in this experiment, arranged in a grid around the center of the screen, such that targets could appear in top-right, top-left, bottom-right, and bottom-left locations. The centers of each of these potential target locations were approximately 5 degrees of visual angle from the center of the screen and from adjacent target locations.

Procedure. The procedure for Experiments 4a and 4b was identical to Experiment 3 with the exception that the location of the target square was assigned randomly to one of four locations. Most important, the imagery and response dimensions were again orthogonal, as in Experiment 3, with participants asked to discriminate whether the notch on the target square was on the left or right side. In Experiment 4a, there was an equal likelihood of congruent and incongruent trials (.50 congruent/.50 incongruent). In contrast, in Experiment 4b, congruent trials were four times more likely than incongruent trials (.80 congruent/.20 incongruent). Following both experiments, participants were asked to provide an estimate of the percentage of trials across the experiment in which they implemented the imagery instruction.

Results

Across both experiments RTs less than 200 ms or greater than 2000 ms were first excluded from analysis (0.6% and 0.1% of RTs excluded in Experiments 4a and 4b, respectively). The remaining correct RTs were then submitted to the same outlier procedure as in prior experiments (2.3% and 2.7% of RTs excluded from Experiments 4a and 4b, respectively). Mean RTs were computed from the remaining observations, and these mean RTs and corresponding error rates were submitted to one-way within-subject ANOVAs that treated cue type (congruent/incongruent) as a factor. Mean RTs for Experiments 4a and 4b are presented in Figure 3, and error rates are displayed in Table 1.

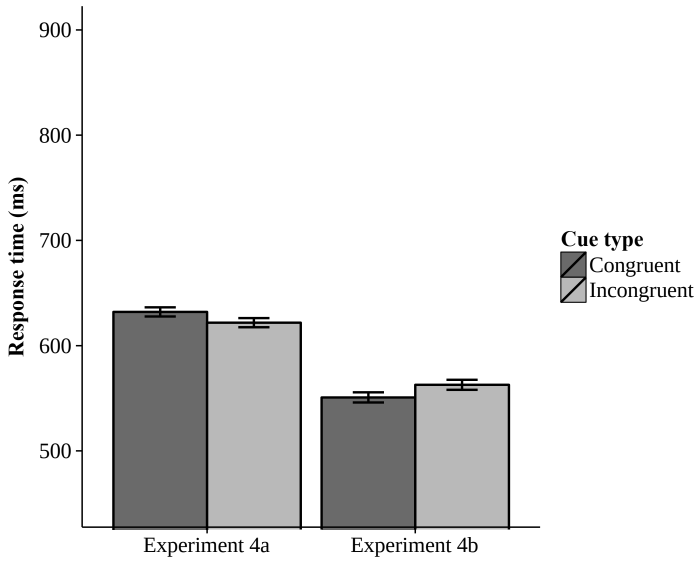

Figure 3. Mean response times for congruent and incongruent cue types for Experiments 4a and 4b. Error bars represent the standard error of the mean corrected for between-subject variability (Cousineau, 2005; Morey, 2008).

Experiment 4a. The analysis of RTs revealed a non-significant effect of cue type, *F*(1,15) = 2.8, *p* = .12, *d* = .05 (congruent = 632 ms, incongruent = 622 ms). In the analysis of error rates, the effect of cue type was also not significant (*p* = .70). Participants reported implementing the imagery instruction on 62.8% of trials.

Experiment 4b. The analysis of RTs again revealed a non-significant effect of cue type, *F*(1,15) = 3.1, *p* = .10, *d* = .12 (congruent = 551 ms, incongruent = 563 ms). In the analysis of error rates, the effect of cue type was again not significant (*p* = .52). Participants reported implementing the imagery instruction on 65.9% of trials.

Combined results. A two-way mixed factor ANOVA of RTs and error rates that treated cue type (congruent/incongruent) as a within-subject factor and experiment (4a/4b) as a between-subjects factor was also conducted. The analysis of RTs revealed a significant interaction between cue type and experiment, *F*(1,30) = 5.9, *p* = .02, η^2_p = .16. This result captures the finding that the non-significant trends in the cue type effect for the two experiments were opposite in sign. There were no significant effects in the analysis of error rates.

Discussion

The purpose of this experiment was to assess whether an imagery effect would be observed in a task that introduces spatial uncertainty of the target. The rationale was that color imagery might benefit localization of a matching colored target, which could in turn produce faster RTs for congruent than incongruent trials. In fact, congruent and incongruent RTs did not differ significantly in either Experiment 4a or Experiment 4b. However, performance did favor congruent relative to incongruent trials more in Experiment 4b than in Experiment 4a, presumably because the imagery cues matched the target color on 80% of trials in Experiment 4b but only 50% of trials in Experiment 4a. Overall, these results offered only modest evidence that mental imagery can act as a target template to speed localization of a lone target.

However, a mental imagery defined target template may be of limited use in localizing a target when that target appears alone in a visual display. Presentation of a lone target could cause attention to be pulled automatically to its location, as shown in the literature on attentional capture by abrupt onsets (Jonides & Yantis, 1988; Theeuwes, 1994; Yantis & Jonides, 1990). As such, it may be that stimulus-driven attentional capture by abrupt onset negated the potential impact of mental imagery in Experiments 4a and 4b.

Experiments 5a and 5b

In Experiments 4a and 4b, target localization may have been driven primarily by abrupt onset, leaving little opportunity for an influence of endogenously cued imagery. To address this issue in the present experiments, four items were now presented together in each target display; a color singleton target and three homogenously colored distractors. Participants now were to search for the color-singleton target (Treisman & Gelade, 1980). In this task, there was onset information available for all four objects. Consequently, we hypothesized that onset information would no longer guide target localization, and endogenously cued color imagery would now have an opportunity to guide target localization (see also Folk, Remington, & Johnston, 1992).

Methods

Participants. Thirty-two undergraduates at McMaster University took part in Experiments 5a (16 participants; 11 female, M_{age} = 19.8 years) and 5b (16 participants; 13 female, M_{age} = 18.3 years) in exchange for course credit. All participants had normal or corrected-to-normal vision.

Apparatus & Stimuli. The apparatus was identical to previous experiments. The stimuli were similar to those in Experiments 4a and 4b, with the exception that each display contained a singleton color target and three homogenously colored distractors. As in Experiments 4a and 4b, there were four possible target locations arranged in a grid around the center of the screen, such that the target appeared in the top-right, top-left, bottom-right, or bottom-left location. The three distractors appeared in the remaining three locations. The target and distractors were either red or green, with the target square being the square that differed in color from the distractors; that is, if the target was red, the three distractors were green, and vice versa.

Procedure. The procedure was similar to Experiments 4a and 4b in that the proportions of congruent and incongruent trials were equal in Experiment 5a (.50 congruent/.50 incongruent), whereas there were four times more congruent than incongruent trials in Experiment 5b (.80 congruent/.20 incongruent). Participants were instructed to indicate the side of the singleton target square (left or right) in which a notch was missing.

Results

Across both experiments, RTs less than 200 ms or greater than 2000 ms were first excluded from analysis (0.7% and 0.4% of RTs excluded from Experiments 5a and 5b, respectively). The remaining correct RTs were submitted to the same outlier procedure as in prior experiments (2.6% and 2.8% of RTs excluded from Experiments 5a and 5b, respectively). Mean RTs were computed from the remaining observations, and these mean RTs and corresponding error rates were submitted to one-way within-subject ANOVAs that treated cue type (congruent/incongruent) as a factor. Mean RTs are displayed in Figure 4, and error rates are displayed in Table 1.

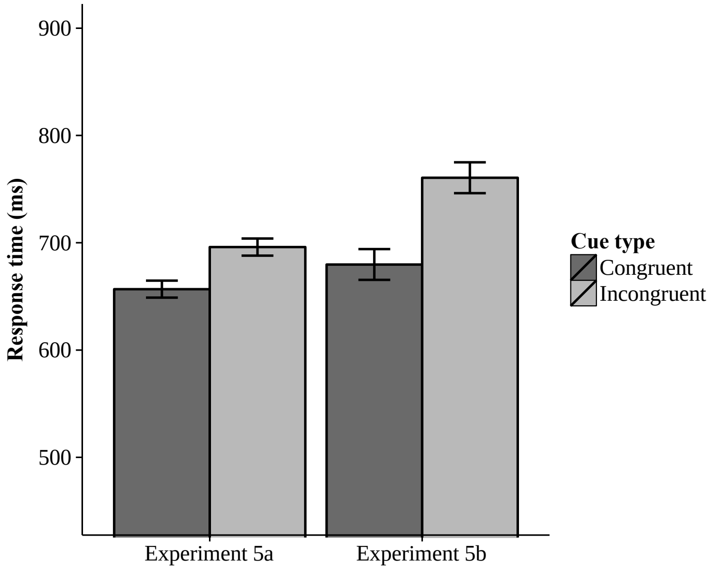

Figure 4. Mean response times for congruent and incongruent cue types for Experiments 5a and 5b. Error bars represent the standard error of the mean corrected for between-subject variability (Cousineau, 2005; Morey, 2008).

Experiment 5a. The analysis of RTs revealed a significant effect of cue type, *F*(1,15) = 12.2, *p* = .003, *d* = 0.32, with faster responses for congruent trials (657 ms) than for incongruent trials (696 ms). The analysis of error rates also revealed a significant effect of cue type, *F*(1,15)

= 5.05, *p* = .04, *d* = .55, with a higher error rate for incongruent trials (5.72%) than for congruent trials (1.69%).

Reliability of the imagery effect across blocks was quite good, *r*(14) = .82, *p* < .001, but the correlation between imagery effects and VVIQ scores was not significant *r*(14) = -.13, *p* = .62. Participants reported implementing the imagery instruction on 69.1% of trials.

Experiment 5b. The analysis of RTs revealed a significant effect of cue type, *F*(1,15) = 15.9, *p* = .001, *d* = 0.71, with faster responses for congruent trials (680 ms) than for incongruent trials (761 ms). In the analysis of error rates, the effect of cue type was not significant (*p* = .17).

Again, the reliability of the imagery effect across blocks was good, *r*(14) = .81, *p* < .001, but the correlation between imagery effects and VVIQ scores was not significant *r*(14) = -.13, *p* = .63. Participants reported implementing the imagery instruction on 73.8% of trials.

Combined results. A two-way mixed factor ANOVA of RTs and error rates that treated cue type (congruent/incongruent) as a within-subject factor and experiment (5a/5b) as a between-subjects factor was also conducted. In the analysis of RTs, there was of course a main effect of cue type, *F*(1,30) = 26.8, *p* < .001, *d* = .51, with faster responses for congruent than for incongruent trials. In addition, the interaction between cue type and experiment approached significance, *F*(1,30) = 3.21, *p* = .08, η^2_p = .10, indicating a trend toward a larger congruency effect in Experiment 5b than in Experiment 5a (see Figure 4). There were no significant effects in the analysis of error rates.

Discussion

The imagery effect was statistically significant in both Experiments 5a and 5b. These results are consistent with the idea that color imagery can influence processes that contribute to target localization when the target must be selected from an array of colored distractors. This finding fits with others reported in the literature suggesting that top-down processes can modulate visual search (Folk et al., 1992; Wolfe, 1994).

With respect to the study of Wantz et al. (2015), these findings are in accord with their general claim that color imagery can impact representations that overlap with those that support color perception. However, the results in Experiments 5a and 5b are not subject to the limitations we highlighted about the method used by Wantz et al. (2015). In particular, the results reported here demonstrate a strong imagery effect under conditions in which the response dimension is orthogonal to the color dimension. The putative color imagery generated by participants in response to the cue offered no information about the correct response for that trial, as the response required a discrimination (is the missing notch on the left or right?) that was orthogonal to the imagined color.

Experiment 6a and 6b

An important issue addressed in the Wantz et al. (2015) study was whether the representations driving the imagery effect were indeed visual rather than verbal. To address this issue in Experiment 2 of their study, they asked participants to perform an articulatory suppression task while generating color imagery in response to the cue. Indeed, the color imagery effect was not affected by articulatory suppression. In Experiments 6a and 6b, we asked whether the imagery effects observed in Experiments 5a and 5b would remain if verbal coding during the imagery task was prevented with articulatory suppression.

Methods

Participants. Thirty-two undergraduates at McMaster University took part in Experiments 6a (16 participants; 12 female, M_{age} = 18.6 years) and 6b (16 participants; 12

female, M_{age} = 18.4 years) in exchange for course credit. All participants had normal or corrected-to-normal vision.

Apparatus & Stimuli. The apparatus and stimuli were the same as in Experiments 5a and 5b.

Procedure. The procedure was similar to Experiments 5a and 5b with the exception that participants were instructed to repeat "ba, ba, ba" aloud during the period when participants were required to generate color imagery (i.e., while the blank box was present on the screen). As in Experiments 5a and 5b, the proportions of congruent and incongruent trials were equal in Experiment 6a (.50 congruent/.50 incongruent), whereas congruent trials were four times more likely than incongruent trials in Experiment 6b (.80 congruent/.20 incongruent). Participants were again instructed to indicate the side of the color singleton target from which the notch was missing.

Results

Across both experiments, RTs less than 200 ms or greater than 2000 ms were excluded from analysis (1.8% and 0.4% of RTs excluded from Experiments 6a and 6b, respectively). The remaining correct RTs were submitted to the same outlier procedure as in prior experiments (2.6% and 2.5% of RTs excluded from Experiments 6a and 6b, respectively). Mean RTs were computed from the remaining observations, and these mean RTs and corresponding error rates were submitted to one-way within-subject ANOVAs that treated cue type (congruent/incongruent) as a factor. Mean RTs are displayed in Figure 5, and error rates are displayed in Table 1.

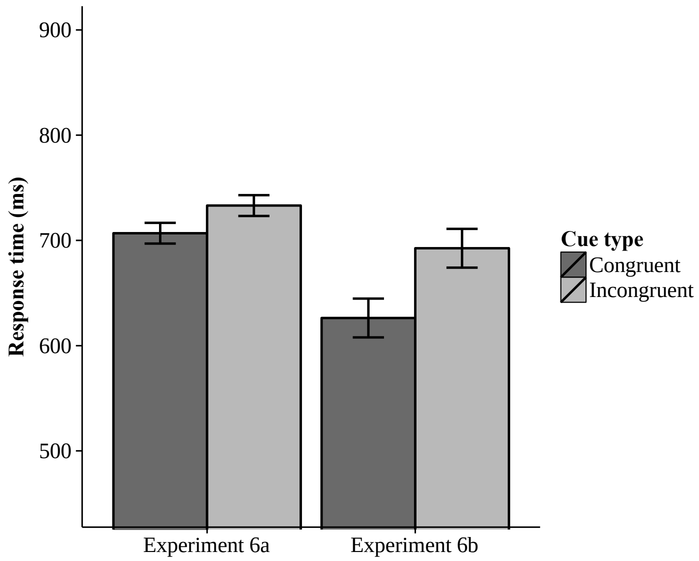

Figure 5. Mean response times for congruent and incongruent cue types for Experiments 6a and 6b. Error bars represent the standard error of the mean corrected for between-subject variability (Cousineau, 2005; Morey, 2008).

Experiment 6a. The analysis of RTs revealed an effect of cue type that approached significance, $F(1,15) = 3.6$, $p = .08$, $d = 0.14$, with faster responses for congruent trials (707 ms) than for incongruent trials (733 ms). In the analysis of error rates, the effect of cue type was not significant ($p = .54$). Participants reported implementing the imagery instruction on 61.9% of trials.

Experiment 6b. The analysis of RTs revealed a significant main effect of cue type, $F(1,15) = 6.5$, $p = .02$, $d = 0.38$, with faster responses for congruent trials (626 ms) than for incongruent trials (692 ms). In the analysis of error rates, the effect of cue type was not significant ($p = .17$).

As in prior experiments, the reliability of the imagery effect across blocks was significant, $r(14) = .93$, $p < .001$, whereas the correlation between imagery effects and VVIQ scores was not significant *r*(14) = .14, *p* = .60. Participants reported implementing the imagery instruction on 66.3% of trials.

Combined results. A two-way mixed factor ANOVA of RTs and error rates that treated cue type (congruent/incongruent) as a within-subject factor and experiment (6a/6b) as a between-subjects factor was conducted. There was a significant main effect of cue type, *F*(1,30) = 9.81, *p* = .004, *d* = .25, reflecting faster responses for congruent trials than for incongruent trials. The interaction was not significant (*p* = .19). There were no significant effects in the analysis of error rates.

Discussion

The purpose of this experiment was to determine whether the imagery effects observed in Experiments 5a and 5b were driven by verbal rather than visual representations of color. Consistent with the findings of Wantz et al. (2015), we found that the imagery effect was present when imagery was cued, generated, and maintained while participants engaged in an articulatory suppression task. As such, this experiment provides converging evidence for the view that the imagery effect reported here is supported by visual rather than verbal representations. As in Experiments 5a and 5b, because the imagery and response dimensions were orthogonal, these effects cannot be attributed activation of response representations in accord with the color cue.

General Discussion

Using a novel methodological approach, Wantz et al. (2015) found that mental imagery of color in response to a cue speeded subsequent identification of matching perceptual colors. They attributed this effect to the activation of visual representations during mental imagery that facilitated color identification. In the present study, we highlighted concerns with the method used by Wantz et al. to draw this conclusion and offered an alternative method that allows a stronger inference that visual representations activated by color imagery in response to a cue can influence performance in a following perceptual task.

In Experiment 1, we replicated the result of Wantz et al. (2015). In Experiment 2, we used a two-color variant of the same task, and ensured that imagery cues did not predict following target colors. This change to the method reduced the size of the congruency effect substantially. In Experiment 3, the response dimension was made orthogonal to the imagined color dimension, and the congruency effect disappeared entirely. In Experiments 4-6, we maintained the methodological constraints imposed in the earlier experiments and explored whether color imagery aids processing in a visual search task. In all of these experiments, participants performed the same task as in Experiment 3, identifying the side on which a notch was missing from a target square, and the target appeared randomly in one of four locations. In Experiments 4a and 4b, a lone target square was presented and the congruency effect was not observed. In Experiments 5a and 5b, a singleton color target square was presented with three homogenously colored distractor squares, and a significant congruency effect was observed. In Experiments 6a and 6b, this congruency effect was again observed when participants completed an articulatory suppression task during color imagery.

Overall, the results not only demonstrate that color imagery can influence performance in a following perceptual task, but they also demonstrate that the link between visual representations activated by color imagery and performance is more compelling in the visual search task used in Experiments 4-6 than in the color identification task used in Experiments 1-3 (see also Wantz et al., 2015). The results of the visual search experiments are more compelling in our view because the congruency effect in these experiments cannot easily be attributed to activation of response representations. This attribution was ruled out by ensuring that the response dimension (i.e., left/right) was orthogonal to the mental imagery dimension (i.e., color) in the visual search experiments. At the same time, we want to be careful to note that response activation may or may not have contributed to the color identification results in Experiments 1 and 2 reported here, and in the study of Wantz et al. Our point is simply that the method used in these experiments cannot rule out this interpretation, whereas the method used in our visual search experiments can rule out this interpretation.

Processes affected by imagery

The methodological concerns raised for Experiments 1 and 2 lead us to conclude that we have little evidence that mental imagery activates perceptual representations that facilitate color identification. On the other hand, the congruency effects in Experiments 5 and 6 suggest that mental imagery does activate representations that can facilitate visual search. What is the nature of these representations that impact visual search?

One possibility is that representations activated by mental imagery speed the localization of visual search targets. This proposal fits with the finding that the congruency effect was robust when a single target was presented with three homogenous distractors but not when a single target was presented on its own. For single targets presented without distractors, target localization may be driven automatically by the lone abrupt onset signal associated with the target. In contrast, for single targets presented with distractors, the match between the imagined color and target color may drive attention toward the location of the target, which in turn speeds search performance. A second possibility is that representations activated by mental imagery facilitate the disambiguation of target from distractors. By this view, the match between the imagined color and target color may drive a process that activates the target representation and inhibits distractor representations, resulting in selection of the target for subsequent localization.

The distinction between these two possibilities may map onto the distinction between dorsal and ventral visual pathways (Milner & Goodale, 1995), with the dorsal pathway implicated if it is target localization that is affected by mental imagery, and the ventral pathway implicated if it is disambiguation of target from distractor that is affected by mental imagery. This is a topic that merits further study.

Mental imagery congruency effects and the VVIQ

An additional interesting finding in the present study concerns the relation between mental imagery processes that drive the congruency effects reported here and subjective reports of mental imagery as indexed by the VVIQ (Marks, 1973). In the present study, we computed the reliability of congruency effects, as well as the correlation between congruency effects and scores on the VVIQ, for all experiments that produced a significant congruency effect (Experiments 1, 2, 5a, 5b, 6b). The congruency effects proved to be highly reliable in all of these experiments, with reliabilities (computed using congruency effects for the two blocks) of at least .80 in all cases. In light of this high reliability, it is noteworthy that correlations between congruency effects and VVIQ scores were not significant in all cases. A summary of this relation is presented in Figure 6, which includes the congruency effects and VVIQ scores for all 80 participants in these five experiments. The correlation across all participants again failed to reach significance, $r = -.14$. We conclude from these results that there is surprisingly little overlap in the processes that contribute to these two measures of mental imagery. It is also notable that the construct validity of the VVIQ has been challenged (Chara, 1989; Chara & Verplanck, 1986; though see Marks, 1989; Mckelvie, 1990; Mckelvie, 1995), and that Wantz et al. (2015) did not find a correlation between their congruency effect and the VVIQ. The distinction between processes responsible for cued color imagery, as in the task used in the present study, and processes that drive responding on the VVIQ is also a topic that merits further study.

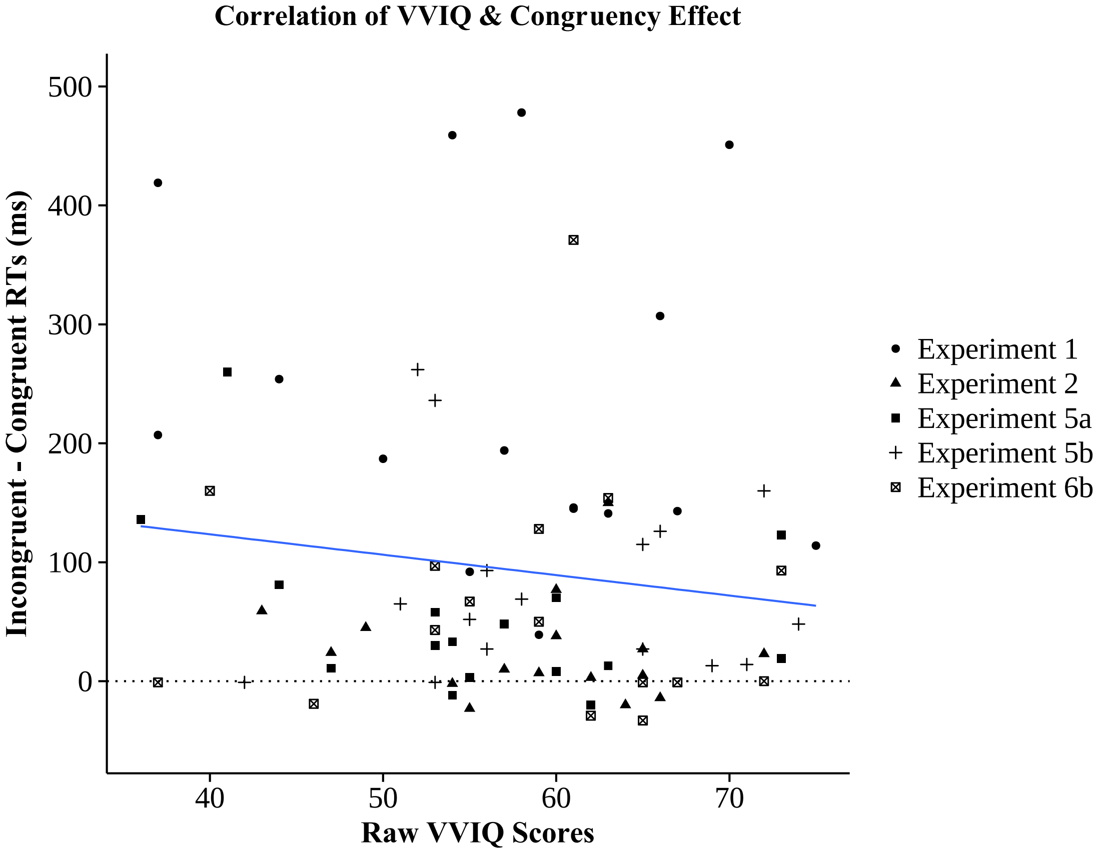

Figure 6. Correlation between raw VVIQ scores and the congruency effect. The congruency effect was operationalized as mean congruent RTs subtracted from mean incongruent RTs for each participant.

Subjective estimates of mental imagery use

In Experiments 4-6 we varied the proportion of trials in which the cued color imagery matched the target color in the visual search task. Although this effect was statistically significant only in Experiments 4a/4b, there was a consistent trend toward larger congruency effects when the proportion of congruent trials was .80 than when it was .50. One interpretation of this result is that participants may have followed the instruction to generate color imagery on a higher proportion of trials when the cue indicated the target color on a high proportion of trials.

We evaluated this idea by asking participants following the experimental session in Experiments 4-6 to provide an estimate of the percentage of trials on which they generated imagery of the cued color. An analysis of these estimates failed to reveal any significant effects. We conclude that different propensities to engage in imagery as a function of proportion congruent is either not well measured by these subjective estimates of imagery use or does not explain the larger congruency effects in the .80 condition. It would be useful in future research to explore other methods of measuring imagery use, such as probing imagery use trial-by-trial (e.g., see Keogh & Pearson, 2017; Pearson, Tong & Rademaker, 2008) rather than just once at the end of the experimental session.

Conclusion

The results of the present study support the general notion advocated by Wantz et al. (2015), that color imagery can influence performance in a following perceptual task. However, the results do not support the view that color imagery impacts color identification processes. Rather, imagery congruency effects in which the response dimension was orthogonal to the imagined dimension (i.e., color) were observed only when visual search for a target among distractors was required. Therefore, the results offer compelling support for the idea that color imagery activates visual representations that guide visual search.

Chapter 4: Imagined event files: An interplay between imagined and perceived objects

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Preface

Chapter 4 presents the results of four experiments in which the influence of color imagery and stimulus-response (S-R) binding effects were evaluated. Participants were required to make an arbitrary response to a stimulus then perform a color discrimination task. The critical manipulation here was the representational basis of the first stimulus, whether it be a perceptual, imagined, or verbal color. The basic finding is that when the S-R bindings across these tasks are either completely the same or different, responding is efficient. However, when there is partial overlap of the S-R bindings across tasks, responding is inefficient – this is thought to reflect an additional process involved with the updating of transient memory representations. Here, we replicated the finding that these processes were operative for perceptual colors, but also observed that this was also the case for imagined and verbal color as well. Overall, this suggests that internal (i.e., imagined or verbal) representations can be bound to external actions.

Abstract

An important function of attention is to integrate features processed in distinct brain areas into a single coherent object representation. The immediate outcome of this binding process has been termed an event file, a transient memory structure that links features, context, and associated actions (Hommel, 2004). A key result that supports the existence of event files is the partial repetition cost – slowed responses to a current event thought to reflect the updating of event file bindings in simple trial-to-trial repetition methods. In four experiments, using a procedure similar to Hommel (1998), we explored whether similar event file binding effects occurred when participants imagine rather than perceive a first event prior to responding to a following visual event. The results indicate that this effect does occur, implying that feature binding in imagery and perception may follow similar principles.

Introduction

The visual world around us contains a rich array of information. To make sense of this complexity, visual features processed in distinct regions of cortex must be integrated into coherent object representations. Kahneman, Treisman, and Gibbs (1992) were among the first to propose a mechanism for dealing with this issue. They suggested that perceptual information is integrated into 'object files', or short-term episodic representations that temporarily link together codes of the relevant features of perceptual objects. This binding proposal has since been expanded to include contextual information and associated actions (Hommel, 1998; Hommel & Colzato, 2004).

Kahneman et al. (1992) highlighted a behavioral consequence of forming an object file using a simple preview letter-naming task. Participants were required to respond to a target letter that matched both the location and identity of a preceding preview letter, or that matched the identity of one preview letter and the location of a different preview letter. Naming responses were faster for the condition in which the target matched both location and identity of a preview letter, implicating some form of memory for the binding between these two features. Kahneman et al. named this effect the object specific preview benefit. Hommel (1998) expanded on this idea by demonstrating that response representations can also be bound together with visual features in these object representations, called 'event files'. Both sets of findings suggest that preview (or repetition) effects do not depend simply on repetition of object features – they also depend on the repetition of feature bindings. When features repeat from preview to target display, but the bindings involving those features change, additional time is needed to update those bindings.

In the present study, we examined whether event file binding can occur for representations that support visual imagery rather than vision itself. The theory of event encoding proposes that event file binding is produced by transient links involving perception and action codes (Hommel, Musseler, Aschersleben, & Prinz, 2001). If vision and visual imagery have common underlying representations (Ishai et al., 1999; Kosslyn, Thompson, & Ganis, 2006; O'Craven & Kanwisher, 2000), then it seems possible that event file binding could occur for representations that support visual imagery. In line with this idea, several recent studies have shown that visual imagery can influence visual search (Cochrane, Nwabuike, Thomson, & Milliken, 2018; Cochrane, Zhu, & Milliken, 2018; Reinhart, McClenahan & Woodman, 2015), binocular rivalry (Chang, Lewis, & Pearson, 2013) and visual identification (Wantz, Borst, Mast, & Lobmaier, 2015; though see Cochrane, Siddhpuria, & Milliken, 2018). Together, the theory of event encoding and the empirical work cited above constitute a solid basis for examining whether representations that support visual imagery can contribute to event file binding. The experiments reported here constitute a first attempt at exploring this issue.

We examined this issue by asking whether visual imagery at one point in time can produce partial repetition costs for a visual object presented at a following point in time. We used an event file procedure derived from the work of Hommel (1998). The first stimulus (S1) on a trial required participants to imagine a color and then make an arbitrary *left*/*right* keypress response. The second stimulus (S2) on a trial was a colored square that required a two-alternative forced-choice *left*/*right* keypress response. If imagined objects involve feature bindings that are similar to those of perceptual objects, then the pattern of event file binding effects ought to be similar for participants who perceive S1 and participants who imagine S1.

Experiment 1

In Experiment 1, repetition effects were compared across two groups, one in which S1 and S2 were both perceptual colors, and another in which S2 was a perceptual color but S1 was an imagined color.

Method

Participants. Thirty-two undergraduates at McMaster University (26 female, M_{age} = 18.2 years) took part in exchange for course credit. Sixteen of the 32 participants were assigned randomly to each of the perception and imagery groups. A power analysis revealed that a sample size of eight participants per group would be sufficient to detect an event file binding effect of the size typically reported in the literature (Cohen's f = .80) with power = .80.

Apparatus and stimuli. Stimuli were presented using Psychopy v1.82 on a BenQ 24-in LED monitor that was connected to a Dell 300 computer. All visual displays were set on a black background. S1 and S2 were centrally located squares that subtended vertical and horizontal visual angles of three degrees. For the perception group, S1 was presented in either red or green. For the imagery group, S1 was a white outline square with a white 'R' or 'G' inside the square. The cue presented prior to S1 was three white carets ('<<<') facing either *left* or *right*. S2 for both the perception and imagery groups was a red or green square.

Procedure. Participants were seated approximately 60 cm from the computer screen. Each trial began with text displayed on screen inviting participants to press the spacebar to begin the trial. Following a spacebar press, a central fixation cross was displayed for 500 ms. Three carets facing either left or right were then presented centrally for 1500 ms, followed by the fixation cross for 500 ms, and then onset of S1. In the perception group, S1 was a centrally located red or green square. In the imagery group, S1 was a centrally located white outline square containing either an 'R' or 'G' (see Figure 1). Participants in the imagery group were instructed to imagine the square was solid green if it contained a 'G' and to imagine it was solid red if it contained an 'R'. Participants in both groups responded to S1 with a keypress indicating the caret direction. Participants in the perception group made this response immediately upon onset of S1, whereas participants in the imagery group made this response when they had completed the imagery task as requested. Participants pressed 'z' if the carets were facing *left* and 'm' if they were facing *right*. Following the response to S1, a centrally located fixation cross was displayed for 1500 ms, followed by S2, a red or green square. Half of the participants responded *red* by pressing the 'z' key and *green* by pressing the 'm' key, while the other half of participants had the opposite response mapping. Following response to S2, participants were prompted onscreen to indicate the vividness of their visual imagery on a 4-point scale: '1 = no imagery', '2 = weak imagery', '3 = moderate imagery', and '4 = strong imagery, almost like perception'.

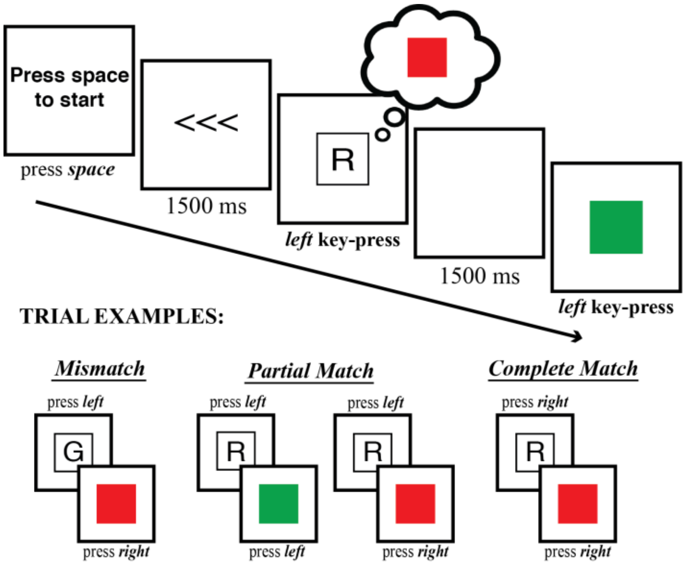

Figure 1. An example of a partial match trial for the imagery group, together with a depiction of the four trial types tested.

The experiment began with 15 practice trials. The first five practice trials required only color identification of S2. The next five practice trials involved the full trial sequence with the exception that responses to the caret direction task were made to a white outline box. For the final five practice trials, participants performed a full trial sequence corresponding to their assigned group. Participants then performed 200 experimental trials.

Results

Mean correct response time (RT) to S2 was the primary dependent variable in all experiments. RTs excluded from these mean RTs included: (1) trials in which an incorrect response was made to S1/S2; (2) correct RTs greater than 2000 ms or less than 200 ms (2.9% of observations); and then (3) correct RTs identified as outliers (3.0% of observations) by the non-recursive moving criterion procedure of Van Selst and Jolicoeur (1994). The resulting mean RTs and corresponding error rates were submitted to separate mixed factor ANOVAs that treated group (imagery/perception) as a between-subjects variable and color (repeat/alternate) and response (repeat/alternate) as within-subject variables. Mean RTs are displayed in Figure 2, and error rates are displayed in Table 1.

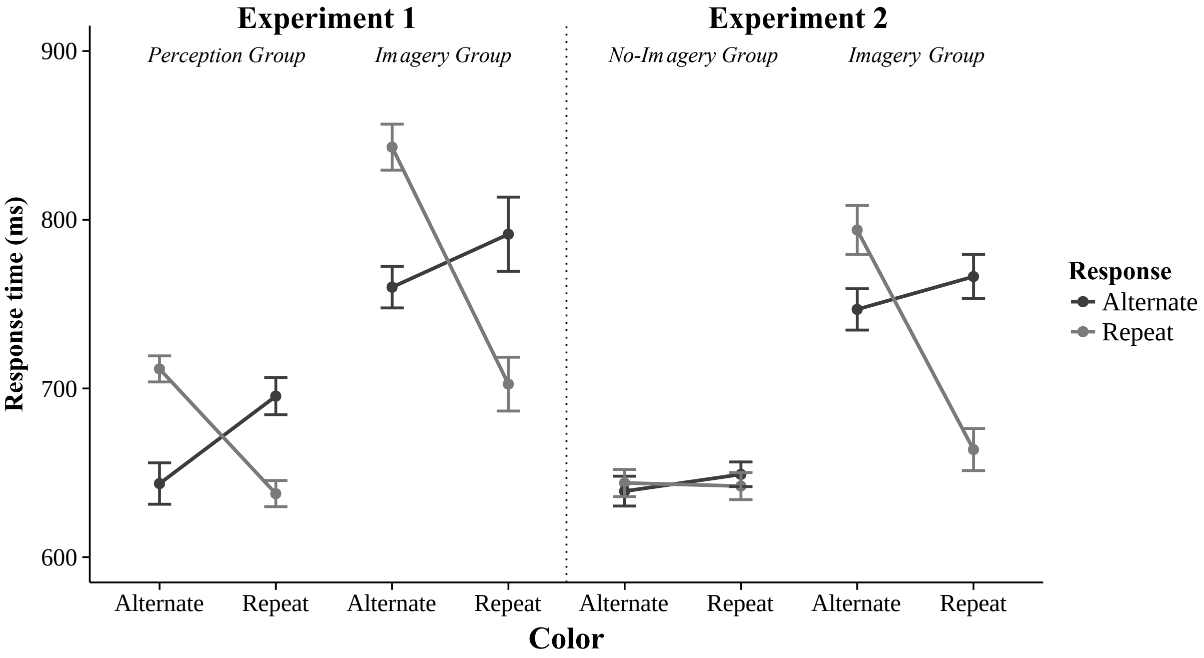

Figure 2. Mean response times for the perception and imagery groups of Experiment 1 and the no-imagery and imagery groups of Experiment 2. Error bars represent the standard error of the mean corrected to remove between-subjects variability (Cousineau, 2005; Morey, 2008).

Table 1. Percentage errors in Experiments 1 and 2.

Trial Type		**Experiment 1**		**Experiment 2**	
Color	*Response*	*Perception*	*Imagery*	*No imagery*	*Imagery*
Alternate	Alternate	2.7	1.9	4.2	1.6
Alternate	Repeat	5.1	6.4	3.4	6.3
Repeat	Alternate	6.4	5.1	5.2	6.0
Repeat	Repeat	1.6	2.4	3.7	1.3

The analysis of RTs revealed a main effect of group that approached significance (p = .07), with slower RTs for the imagery group. The interaction between color and response was also significant, $F(1,30) = 43.5$, $p < .001$, $\eta^2_p = .59$, implying that event file binding effects did indeed occur in our study. This interaction did not differ statistically for the perception and imagery groups (p = .31, for the three-way interaction). As our primary interest was whether event file binding would occur for each of the perception and imagery groups, separate two-way repeated measures ANOVAs were then conducted for each group.

Perception group. In the analysis of RTs, there was a significant interaction between color and response, $F(1,15) = 23.9$, $p < .001$, $\eta^2_p = .61$. For the color alternate condition, responses were faster for the response alternate than response repeat condition, $F(1,15) = 21.2$, $p < .001$, $d = .40$. In contrast, for the color repeat condition, responses were faster for the response repeat than response alternate condition, $F(1,15) = 19.2$, $p < .001$, $d = .32$.

In the analysis of error rates, there was also a significant interaction between color and response, $F(1,15) = 16.7$, $p < .001$, $\eta^2_p = .61$. For the color alternate condition, the effect of response repetition was not significant ($p = .18$). For the color repeat condition, fewer errors were made for the response repeat than response alternate condition, $F(1,15) = 12.6$, $p = .001$, $d = .67$.

Imagery group. In the analysis of RTs, there was a significant main effect of color, with faster responses for the color repeat than color alternate condition, $F(1,15) = 11.3$, $p = .004$, $\eta^2_p = .34$. More important, there was a significant interaction between color and response, $F(1,15) = 21.5$, $p < .001$, $\eta^2_p = .59$. For the color alternate condition, responses were faster for the response alternate than response repeat condition, $F(1,15) = 24.8$, $p < .001$, $d = .54$. For the color repeat condition, responses were faster for the response repeat than response alternate condition, $F(1,15) = 8.62$, $p = .01$, $d = .60$.[9]

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[9] Additional within-subject analyses of RTs for the imagery group were conducted that treated vividness ratings as a factor to evaluate whether the event file binding effect occurred for reports of 'no imagery'. To maximize sensitivity, we included all 64 imagery group participants across all 4 experiments and compared reports of 'no imagery' (vividness ratings of 1) to all reports of imagery (vividness ratings of 2, 3, and 4). Due to the rarity of 'no imagery' responses, all but 12 participants were excluded from analyses. The analyses of RTs revealed a significant event file binding effect for reports of imagery ($F(1,11) = 14.4$, $p = .002$, $\eta^2_p = .57$) with faster responses for response repeats (740 ms) relative to alternates (822 ms) in the color repeat condition ($F(1,11) = 13.7$, $p = .003$, $d = .47$), and faster responses for response alternates (778 ms) relative to repeats (829 ms) in the color alternate

In the analysis of error rates, the interaction between color and response was significant, $F(1,15) = 8.46$, $p = .01$, $\eta^2_p = .36$. For the color alternate condition, there were fewer errors for the response alternate than response repeat condition, $F(1,15) = 11.5$, $p = .004$, $d = .75$. For the color repeat condition, there were fewer errors for the response repeat than response alternate condition, $F(1,15) = 12.6$, $p = .001$, $d = .67$.

Discussion

The results in the perception group replicated those reported in many prior studies (e.g., Hommel, 1998; 2004), with the effect of color repetition strongly dependent on the influence of response repetition. Most important, the results in the imagery group revealed a qualitatively similar interaction, with the effect of color repetition again strongly dependent on the influence of response repetition. This interaction is consistent with the proposal that visual imagery and visual perception involve similar event file binding processes. In addition, and of less importance, the trend toward slower responses in the imagery group than the perception group perhaps points to a task switching cost across S1/S2 tasks.

Experiment 2

As a control for Experiment 1, we examined whether the pattern of results for the imagery group hinged on the imagery instruction, rather than the mere S1 presentation – the 'R' and 'G'. Two groups were tested in Experiment 2: a replication of the imagery group from Experiment 1, and a control group with identical S1 and S2 stimuli but no imagery instruction.

Method

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condition ($F(1,11) = 5.90$, $p = .03$, $d = .26$). There were no significant effects for reports of 'no imagery' (all $F <$ 1.5), reflecting a null RT difference for response repeats (868 ms) relative to alternates (835 ms) in the color repeat condition ($p = .62$), and for response alternates (824 ms) relative to repeats (897 ms) in the color alternate condition ($p = .13$). This finding offers preliminary support that event binding effects were only present when participants generated imagery.

Participants. Thirty-two undergraduates at McMaster University (27 female, M_{age} = 18.0 years) took part in exchange for course credit. Sixteen of 32 participants were assigned randomly to each of the imagery and no-imagery groups.

Apparatus and stimuli. The apparatus and stimuli were identical to those in the imagery group of Experiment 1.

Procedure. The procedure for the imagery group was identical to Experiment 1. The procedure for the no-imagery group was similar, with the exception that participants were not instructed to imagine a color in response to S1.

Results

Correct RTs greater than 2000 ms or less than 200 ms (1.4% of observations) and correct RTs identified by the Van Selst and Jolicoeur (1994) outlier method (2.8% of observations) were excluded from analyses. Mean RTs and error rates for the imagery and no-imagery groups were submitted to mixed factor ANOVAs as in Experiment 1. Mean RTs are displayed in Figure 2, and error rates are displayed in Table 1.

The analysis of RTs revealed a main effect of group that approached significance (p = .051), with higher RTs for the imagery group than the no-imagery group. Importantly, there was a significant three-way interaction between color, response, and group, $F(1,30) = 12.38$, p = .001, $\eta^2_p = .29$. Separate repeated measures ANOVAs were then conducted for each group.

Imagery group. The analysis of RTs revealed significant main effects of both color and response, with faster responses to the color repeat than color alternate condition, $F(1,15) = 16.0$, $p = .001$, $\eta^2_p = .52$, and faster responses to the response repeat than response alternate condition, $F(1,15) = 12.1$, $p = .003$, $\eta^2_p = .45$. Critically, there was a significant interaction between color and response, $F(1,15) = 19.0$, $p < .001$, $\eta^2_p = .55$. For the color alternate condition, responses were faster for the response alternate than response repeat condition, *F*(1,15) = 5.8, *p* = .03, *d* = .27. For the color repeat condition, responses were faster for the response repeat than response alternate condition, *F*(1,15) = 31.6, *p* < .001, *d* = .66.

The analysis of error rates also revealed a significant interaction between color and response, *F*(1,15) = 13.4, *p* = .002, η^2_p = .47. For the color alternate condition, there were fewer errors for the response alternate than response repeat condition, *F*(1,15) = 11.1, *p* = .004, *d* = .83. For the color repeat condition, there were fewer errors for the response repeat than response alternate condition, *F*(1,15) = 12.3, *p* = .001, *d* = .57.

No-imagery group. There were no significant effects in the analysis of either RTs or error rates (all F < 1).

Discussion

This experiment replicated the results of the imagery group from Experiment 1 and demonstrated a dependence of this pattern of results on the imagery instructions – when no instructions were given to participants for S1, no event file binding effects occurred. At the same time, we must acknowledge that the no-imagery instructions may have failed to produce event binding effects because participants attended only to the onset of S1; that is, a response was made upon onset of S1 without a requirement for any additional processing of S1.

Experiments 3 and 4

In the final two experiments, we examined more closely the types of S1 processing that produce event file binding effects, and in particular whether verbal rather than visual representations could be responsible for event file binding effects observed with visual imagery instructions. In Experiment 3 we evaluated whether event file binding effects would emerge with instructions to verbalize rather than to imagine the S1 color, and in Experiment 4 we evaluated whether visual imagery instructions would produce event file binding effects while verbal coding was occupied by an articulatory suppression task.

Method

Participants. Thirty-two undergraduates at McMaster University (26 female, M_{age} = 18.1 years) were assigned randomly to either the imagery or verbal group in Experiment 3. Sixteen McMaster University undergraduates (14 female, M_{age} = 18.4 years) participated in Experiment 4.

Apparatus and stimuli. The apparatus and stimuli were identical to previous experiments.

Procedure. The procedure for the imagery group of Experiment 3 was the same as in previous experiments. The procedure for the verbal group of Experiment 3 required participants to say aloud 'red' in response to the letter 'R' and 'green' in response to the letter 'G' prior to responding to the caret direction task.[10] In Experiment 4, the procedure was identical to the imagery group of previous experiments with the exception that participants were also required to repeat the phrase 'ba, ba, ba' from onset of presentation of the carets to onset of S2.

Results

Experiment 3. Correct RTs greater than 2000 ms or less than 200 ms (4.7% of observations) and RTs identified by the Van Selst and Jolicoeur (1994) outlier method (2.3% of observations) were excluded from analyses. Mean RTs and error rates for the imagery and verbal groups were submitted to mixed factor ANOVAs as in previous experiments. Mean RTs are displayed in Figure 3, and error rates are displayed in Table 2.

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[10] To ensure the verbal and imagery groups were comparable, participants rated each of their verbal response on a 4-point scale: '1 = no verbalization', '2 = verbalization with uncertain accuracy', '3 = accurate verbalization with weak articulation', and '4 = clear and accurate articulation'.

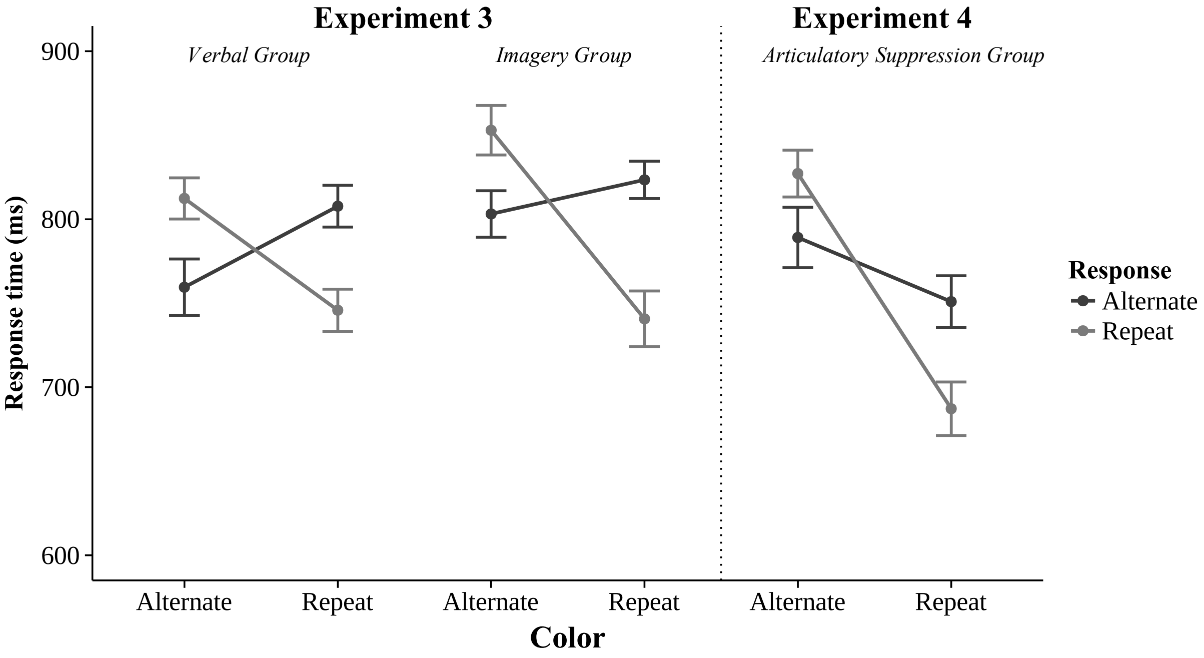

Figure 3. Mean response times for the verbal and imagery groups of Experiment 3 and the articulatory suppression group of Experiment 4. Error bars represent the standard error of the mean corrected to remove between-subjects variability (Cousineau, 2005; Morey, 2008).

Table 2. Percentage errors in Experiments 3 and 4.

Trial Type		**Experiment 3**		**Experiment 4**
Color	*Response*	*Verbal*	*Imagery*	*Articulatory Suppression*
Alternate	Alternate	1.8	2.4	2.9
Alternate	Repeat	5.1	5.0	6.7
Repeat	Alternate	5.2	5.9	5.9
Repeat	Repeat	1.4	2.4	2.1

The analysis of RTs revealed a non-significant three-way interaction between color, response, and group (p = .70). Nonetheless, a priori hypotheses led us to conduct separate two-way repeated measures ANOVAs for each group.

Imagery group. The analysis of RTs revealed a significant main effect of color, with faster responses for the color repeat than color alternate condition, $F(1,15) = 9.89$, $p = .007$, $\eta^2_p =$

.40. Critically, there was also a significant interaction between color and response, *F*(1,15) = 13.8, *p* = .002, η^2_p = .48. For the color alternate condition, responses were faster for the response alternate than response repeat condition, *F*(1,15) = 5.6, *p* = .03, *d* = .24. For the color repeat condition, responses were faster for the response repeat than response alternate condition, *F*(1,15) = 16.1, *p* = .001, *d* = .38.

The analysis of error rates also revealed a significant interaction between color and response, *F*(1,15) = 14.2, *p* = .002, η^2_p = .49. For the color alternate condition, there were fewer errors in the response alternate than response repeat condition, *F*(1,15) = 7.65, *p* = .01, *d* = .52. For the color repeat condition, there were fewer errors in the response repeat than response alternate condition, *F*(1,15) = 10.7, *p* = .005, *d* = .63.

Verbal group. In the analysis of RTs, there was a significant interaction between color and response, *F*(1,15) = 16.2, *p* = .001, η^2_p = .52. For the color alternate condition, responses were faster for the response alternate than response repeat condition, *F*(1,15) = 5.4, *p* = .03, *d* = .29. For the color repeat condition, responses were faster for the response repeat than response alternate condition, *F*(1,15) = 11.9, *p* = .004, *d* = .32.

In the analysis of error rates, there was a significant interaction between color and response, *F*(1,15) = 20.6, *p* < .001, η^2_p = .58. For the color alternate condition, there were fewer errors in the response alternate than response repeat condition, *F*(1,15) = 12.6, *p* = .003, *d* = .83. For the color repeat condition, there were fewer errors in the response repeat than response alternate condition, *F*(1,15) = 22.7, *p* < .001, *d* = 1.10.

Experiment 4. Correct RTs greater than 2000 ms or less than 200 ms (3.3% of observations) and correct RTs identified by the Van Selst and Jolicoeur (1994) outlier method (2.9% of observations) were excluded from analyses. Mean RTs and error rates were submitted to repeated measures ANOVAs that treated color (repeat/alternate) and response (repeat/alternate) as factors. Mean RTs are displayed in Figure 3, and error rates are displayed in Table 2.

The analysis of RTs revealed a significant main effect of color, with faster responses for the color repeat than color alternate condition, $F(1,15) = 15.3$, $p = .001$, $\eta^2_p = .50$. There was also a significant interaction between color and response, $F(1,15) = 37.4$, $p < .001$, $\eta^2_p = .71$. For the color alternate condition, responses were faster for the response alternate than response repeat condition, $F(1,15) = 4.7$, $p = .05$, $d = .21$. For the color repeat condition, responses were faster for the response repeat than response alternate condition, $F(1,15) = 15.4$, $p = .001$, $d = .42$.

The analysis of error rates also revealed a significant interaction between color and response, $F(1,15) = 5.9$, $p = .03$, $\eta^2_p = .28$. For the color alternate condition, there were fewer errors in the response alternate than response repeat condition, $F(1,15) = 4.98$, $p = .04$, $d = .61$. For the color repeat condition, there were fewer errors in the response repeat than response alternate condition, $F(1,15) = 6.11$, $p = .03$, $d = .60$.

Discussion

Event file binding effects were observed for both the imagery and verbal groups in Experiment 3, demonstrating the novel finding that verbal representations can also produce event file binding effects. These results suggest that verbal representations could conceivably underlie event file binding effects observed with visual imagery instructions. However, the results of Experiment 4, in which participants engaged in concurrent visual imagery and articulatory suppression, demonstrate that event file binding effects observed with visual imagery instructions do not depend on verbal coding of S1.

General Discussion

The results of the present study demonstrate the novel finding that bindings can be formed between imagined colors and actions, just as they are formed between perceptual colors and action. Moreover, these bindings contribute to repetition effects between consecutive S1 and S2 items. S2 trials in which the bindings repeat from S1, or S2 trials in which entirely new bindings are formed, are responded to more efficiently than trials in which S1 bindings partially match with those required for S2. These partial match binding effects were present when S1 colors were imagined, verbalized, and imagined during articulatory suppression, but not present when participants were given no instructions for S1 other than to perform an already prepared response. Overall, the results suggest that color imagery produces event file bindings that are sufficiently perception-like to influence performance with perceptual objects.

A finding of particular interest was that event file binding effects were observed with both imagery and verbal instructions in Experiment 3. In some ways, this finding fits with the literature, and in other ways not. Prior studies have shown that verbal representations sometimes have only a modest influence on visual search performance (Cochrane, Nwabuike, Thomson, & Milliken, 2018; Theeuwes, Reimann, & Mortier, 2006). On the other hand, there are also theoretical accounts that posit semantic information is represented in the same brain networks that represent perceptual information (Amsel, Urbach, & Kutas, 2014; Barsalou, 2008; Tomasello et al., 2017). These theories would predict that saying a color aloud should automatically induce activation of a color representation that is visual in nature. We suspect that this was indeed the case in our study – half of the participants in the verbal group of Experiment 3 reported imagining the color when they named it. Ultimately, whether event file binding effects for verbal and visual imagery instructions involve separate or overlapping representations awaits further study.

Chapter 5: The representational basis of non-spatial facilitation and inhibition effects

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Preface

Chapter 5 presents the results of five experiments where the representational basis of the non-spatial facilitation and inhibition effects were explored. In typical two-alternative choice discrimination (2AFC) tasks participants respond faster when targets are repeated across trials than when they alternate. However, when an event intervenes between trials of this task, participants respond faster when the targets alternate than when they remain the same across trials. We explored the representational basis of these effects by having participants perform a 2AFC task where trials were presented in pairs. Here the target of the second trial in a pair was always a perceptual color, and the target of the first trial in a pair was alternated across experiments. It was observed that when the first targets were either imagined or perceptual colors, a facilitation effect was present when no event intervened, and an inhibition effect was present when an event intervened. When the first target was either color representations that were not imagined or extraneous to color, there was an inhibition effect for both event and no-event conditions. Overall, this suggests that facilitation effects depend on the perceptual overlap of targets, whereas the inhibition effects reflect a more complicated relationship with stimulus and response features.

Abstract

Repetition of non-spatial task-related features in performance tasks can produce either a facilitation effect or an inhibition effect. Here, we explore the representational basis of these facilitation and inhibition effects, specifically for color repetition, and making use of color imagery as a tool. Participants imagined red or green in response to the target letter ‘R’ or ‘G’, and then identified a red or green target color by key-press. An intervening event appeared between the two targets on some trials and not on other trials. Color imagery produced facilitation and inhibition effects that were similar to color perception, and the pattern of effects appeared to depend on representational overlap for consecutive targets. When the first of two targets was either a color or a letter that cued color imagery, a facilitation effect with no intervening event gave way to an inhibition effect with an intervening event. When the first target was a letter unaccompanied by color imagery, an inhibition effect was observed both with and without an intervening event. These results suggest that the facilitation effect depends on overlap of visual representations across consecutive targets, whereas the inhibition effect reflects a more complex relationship between stimulus and response features across targets.

Introduction

A classic finding in cognitive psychology is that when a cue (e.g., a color or letter) is presented prior to a target, discrimination responses are faster when the cue and target are the same than when they are different (Rosch, 1975; Posner & Mitchell, 1967; Beller, 1971). A related finding is that identification responses to consecutive targets are faster when those targets are the same than when they are different (Bertelson, 1961; Rabbit, 1968). There has been much debate regarding the representational basis of these facilitation effects – that is, the extent to which these effects depend on stimulus and response features of the target (Pashler & Baylis, 1991; Hommel, 1998). A lesser known finding is that these facilitation effects can reverse to inhibition effects when an intervening event appears between cue and target (Law, Pratt & Abrams, 1995), or between consecutive targets (Spadaro, He, & Milliken, 2012). The present study focuses on the representational basis of these facilitation and inhibition effects in a simple color identification task, with an emphasis on color imagery as a tool to explore this issue.

The first study to demonstrate a color-based inhibition effect was reported by Law, Pratt, and Abrams (1995). Law et al. used a cuing procedure in which a color patch (the cue) was displayed prior to a detection task that required participants to indicate the presence of a second color patch (the target) with a press of the spacebar. The cue and target were either the same or different colors (red or blue). Importantly, an irrelevant magenta color patch was displayed in the interval between presentation of the cue and target on some trials and not on other trials. An inhibition effect was observed when the magenta color patch was present, whereas no difference in response times was observed when the magenta color patch was absent. These results demonstrate that an inhibitory cueing effect can occur for non-spatial attributes of a stimulus when an intervening event appears between cue and target.

Whereas Law et al. (1995) used a cue-target method to demonstrate an inhibition effect in target detection, non-spatial inhibition effects have since been reported in both cue-target (Francis & Milliken, 2003) and target-target variants of discrimination tasks (Spadaro et al., 2012; Spadaro & Milliken, 2013). Spadaro et al. instructed participants to indicate with a key-press whether a target rectangle was blue or yellow for each of two consecutive displays on each trial. On some trials these target colors matched and on other trials the target colors mismatched. An intervening event (a red dot) was displayed temporally between these two targets on some trials and not on others; participants were to press the spacebar in response to the intervening event. In line with many prior studies of trial-to-trial repetition effects (Bertelson, 1961; Rabbitt, 1968; Pashler & Baylis, 1991), a facilitation effect was observed when there was no intervening event between targets. In contrast, the opposite result (i.e., an inhibition effect) was observed when an intervening event appeared (and was responded to) between consecutive targets. Again, this result demonstrates that an inhibitory repetition effect can occur for non-spatial attributes of a stimulus, this time in a discrimination task, but it hinges on the presence of an intervening event between targets.

Theoretical Accounts of Non-Spatial Facilitation and Inhibition Effects

Several theories have been proposed to explain this pattern of facilitation and inhibition effects in tasks with non-spatial stimuli. A first theory is that facilitation and inhibition effects in non-spatial tasks are driven by the same processes as facilitation and Inhibition of Return (IOR; Posner & Cohen, 1984) effects in spatial tasks (Law et al., 1995). Although such a view may be favored by some on grounds of parsimony, others have opposed this theory on grounds that non-spatial facilitation and inhibition effects do not follow the same time course as spatial facilitation and IOR effects (Taylor & Klein, 1998; but see Francis & Milliken, 2003). Taylor and Klein used an experimental procedure similar to Law et al., but they varied the duration of the inter-trial interval (ITI; 150 ms, 300 ms, 450 ms, 600 ms, and 700 ms) between cue and target. Taylor and Klein reported an inhibitory effect that was constant across ITI. The different time course of this effect than is typically observed in studies of spatial cueing therefore argues against these effects having the same cause.

Taylor and Klein (1998) proposed instead that these inhibitory effects are likely due to the processes that drive repetition blindness, an effect by which participants frequently miss the second presentation of a repeated stimulus when it is presented soon after the first one (Kanwisher, 1987, 1991). Fox and de Fockert (2001) forwarded the same theory after finding that the non-spatial inhibition effect disappeared for stimuli presented at peripheral locations rather than at fixation. Further, the magnitude of the non-spatial inhibition effect declined with increasing ITI, a pattern of results at odds with the idea that spatial IOR and non-spatial inhibition effects have the same cause. However, Riggio, Patteri, and Umilta (2004) followed up on the study by Fox and de Fockert (2001) and found that identical cue-target pairs (e.g., a-a) produced repetition costs, but that this was not the case for visually different pairs of the same category (e.g., A-a) – a result that is at odds with repetition blindness effects in the literature (Bavelier & Potter, 1992; Bavelier, 1994; Kanwisher, 1987).

Lupiáñez (2010) has proposed a three-factor model that postulates that facilitation and inhibition effects depend on the timing of stimulus presentation and on the nature of the task performed. Two of these factors are sensitive to the spatial relation between the cue and target and facilitate performance when the cue and target appear at the same location. The third factor is sensitive to the non-spatial features of the object, slowing responses when cue and target are similar in identity. This slowing of performance on related trials is presumed to reflect difficulty in detection of target onset. Lupiáñez argued that this onset detection factor reflects processes that govern the encoding of object files (Kahneman, Treisman, & Gibbs, 1992). When two stimuli that are similar are presented close in time, the second stimulus is integrated into the object file set up by the first stimulus, obscuring onset of the second stimulus. This idea fits well with the results of Hu, Samuel, and Chan (2011). In their study, participants detected the onset of targets that either matched or mismatched a preceding cue, while the location of the cue and target also varied. A non-spatial inhibition effect was observed when the cue and target identity matched, but this inhibition effect occurred only when the cue and target were presented at the same location. Hu et al. interpreted this finding to suggest that a cost in detecting event onset (or some type of feature-based habituation) was responsible for non-spatial inhibition effects (for similar results see Hu & Samuel, 2011; Hu, Fan, Samuel, & He, 2013).

A related idea was offered by Spadaro et al. (2012). They proposed that non-spatial facilitation and inhibition effects observed in target-target discrimination tasks are due to two separate processes. In the absence of an intervening event between target displays, responses are fast when targets match across consecutive displays because response to the second target is facilitated by efficient retrieval of an episodic stimulus-response (S-R) binding (e.g., blue target-right response) from the first target. In contrast, when an intervening event is presented between target displays, the intervening event disrupts this retrieval process, eliminating the process that produces facilitation. The relatively slow responses to match trials with intervening events are then attributed to a second process, one that reflects habituated attention to the second target when it matches the first target.

Visual Imagery and Non-spatial Facilitation and Inhibition Effects

In the present study, our objective was to gain a better understanding of the processes that underlie non-spatial facilitation and inhibition effects by examining how such effects are influenced by visual imagery. A number of parallel results between visual imagery and visual perception have been reported recently. These imagery effects have been demonstrated in visual search (Cochrane, Nwabuike, Thomson, & Milliken, 2018; Cochrane, Zhu, & Milliken, 2018; Reinhart, McClenahan & Woodman, 2015; though see Clarke, Barr, & Hunt, 2016), binocular rivalry (Chang, Lewis, & Pearson, 2013; Pearson, Clifford, & Tong, 2008; Pearson, Rademaker, & Tong, 2011) and object identification (Wantz, Borst, Mast, & Lobmaier, 2015; though see Cochrane, Siddhpuria, & Milliken, 2018). A broad goal of the present study, therefore, was to examine whether non-spatial facilitation and inhibition effects would generalize from procedures that involve visual perception to those that instead involve visual imagery.

A particularly relevant result was reported recently by Cochrane and Milliken (2019). Participants were cued to imagine a color and, once that imagery was generated, to make an arbitrary key-press response based on an arrow cue (*left* or *right*) that was presented earlier in the trial sequence. Participants then performed a color discrimination task, indicating by key-press whether a target colored square was red or green. Importantly, the key-press responses following the imagery and in the color discrimination task overlapped to produce stimulus-response (S-R) bindings that matched, mismatched, or partially matched. Performance on the color discrimination task depended critically on these S-R bindings, in keeping with principles of the theory of event coding (TEC; Hommel, 1998; Hommel, 2004; Hommel, Musseler, Aschersleben, & Prinz, 2001). Specifically, responses were fast when the imagined color and response perfectly matched or mismatched those in the color discrimination task. However, performance was slow in comparison when there was a partial-match of S-R bindings across the imagery and color discrimination tasks. This result suggests that imagery can induce transient representations that produce results in line with TEC. Here, we examined whether imagined representations might also induce non-spatial facilitation and inhibition effects.

We used a target-to-target procedure quite similar to that of Spadaro et al. (2012). Over the course of five experiments, we aimed to vary the representational overlap of the first and second targets while fixing the second target to be a perceptual color. The results of the experiments demonstrate that whether or not intervening events mediate non-spatial facilitation and inhibition effects depends on the representational overlap of first and second targets. These results suggest that a new framework is required to explain non-spatial facilitation and inhibition effects.

Experiment 1

In this first experiment we replicated the basic non-spatial facilitation and inhibition effects with perceptual colored targets reported by Spadaro et al. (2012). Participants identified colored squares (‘red’ or ‘green’) by key-press. In the no-event block of trials, participants performed this task with a blank interval between two targets on each trial. In the event block of trials, a different color square (‘purple’ or ‘yellow’) was presented between target squares and participants named the color of this square aloud. If our results are in keeping with those of Spadaro et al. (2012), then we should find a facilitation effect for the no-event block of trials, and an inhibition effect for the event block of trials.

Method

Participants. Twenty undergraduates at McMaster University (13 female, $M_{\text{age}} = 19.4$ years) took part in exchange for course credit. All participants reported normal or corrected-to-normal vision. Power analyses were conducted to establish appropriate sample sizes using

G*Power version 3.1.9.2. Effect sizes for the interaction between block and trial type ($\eta^2_p = .56$) and the simple main effects of trial type ($\eta^2_p = .35$) were drawn from a comparable experiment reported by Spadaro et al. (2012). Cohen's *f* was computed from η^2_p values as described by Cohen (1988). These analyses revealed that a sample size of 20 participants was sufficient to detect both the interaction and simple main effects with power greater than .80 (all Cohen's $f > .66$).

Apparatus and stimuli. Stimuli were presented using Psychopy v1.83 on a BenQ 24-inch LED monitor that was connected to a Mac Mini computer. All displays were presented on a black background. Target squares were centrally located, always presented in either red or green, and subtended horizontal and vertical visual angles of approximately 2 degrees. Distractor squares followed the same specifications except that they were always presented in purple or yellow.

Procedure. Participants were seated approximately 60 cm from the computer screen. Each trial began with a blank display that lasted 500 ms, followed by the presentation of the first target square. Targets were either 'red' or 'green' and occurred with equal likelihood. Participants responded to the target color by pressing the 'z' or 'm' key on a standard QWERTY keyboard – the color corresponding to each key was counterbalanced across participants. For the no-event block of trials, a blank screen was displayed for 2000 ms following a response to the first target. A second target square was then displayed for 32 ms and participants once again responded to the color by pressing the 'z' or 'm' key. For the event block of trials, a distractor square was presented for 1000 ms following a response to the first target. The distractor square was equally likely to be either 'yellow' or 'purple'. Participants responded to the distractor by saying its color aloud. At offset of the distractor square, a blank screen was displayed for 1000 ms prior to the onset of the second target.

Prior to each of two blocks of trials, participants performed 15 practice trials. Following the practice phase of each block, participants completed a block of 150 trials, for a total of 300 experimental trials. The order of event and no-event blocks was counterbalanced across participants. Within each block, the target colors matched on half of trials (congruent trials) and mismatched on the other half (incongruent trials). An example of a typical trial is depicted in Figure 1.

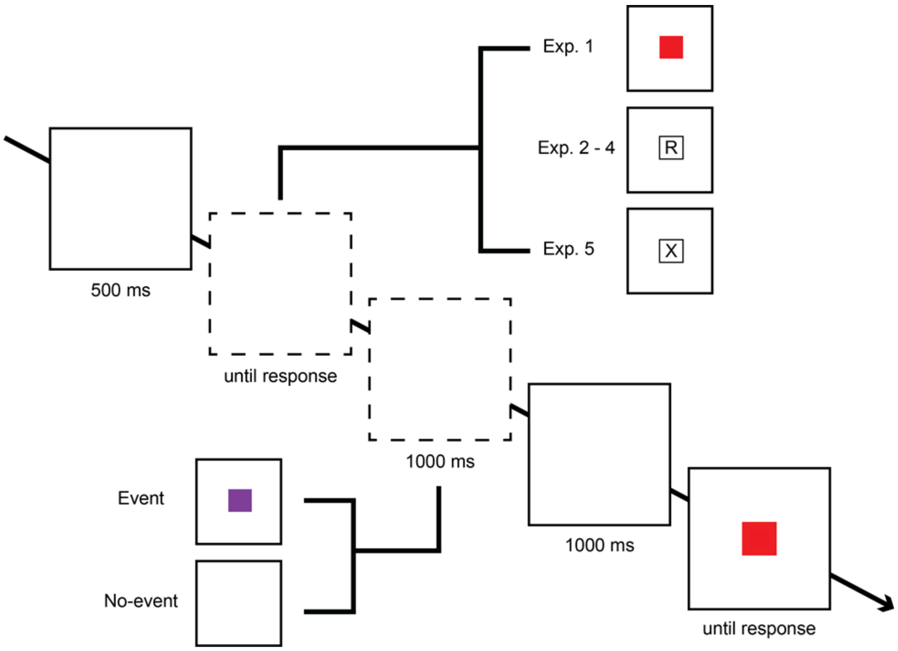

Figure 1. This is an example of a typical trial across the five experiments.

Results

The analyses in all experiments reported here focused on performance for the second of two targets on each trial. Response times (RTs) that were less than 200 ms or greater than 2000 ms were excluded from analysis, which led to the removal of 2.6% of observations. The remaining correct RTs were submitted to the non-recursive outlier elimination procedure of Van

Selst and Jolicoeur (1994), which removed an additional 3.2% of correct RTs from analysis. Mean RTs were computed from the remaining observations, and these mean RTs and corresponding error rates were submitted to within-subject ANOVAs that treated trial type (congruent/incongruent) and block (event/no-event) as factors. An alpha criterion of .05 was used to determine statistical significance in all analyses reported in this article. Mean RTs in Experiment 1 are depicted in Figure 2 and error percentages are displayed in Table 1.

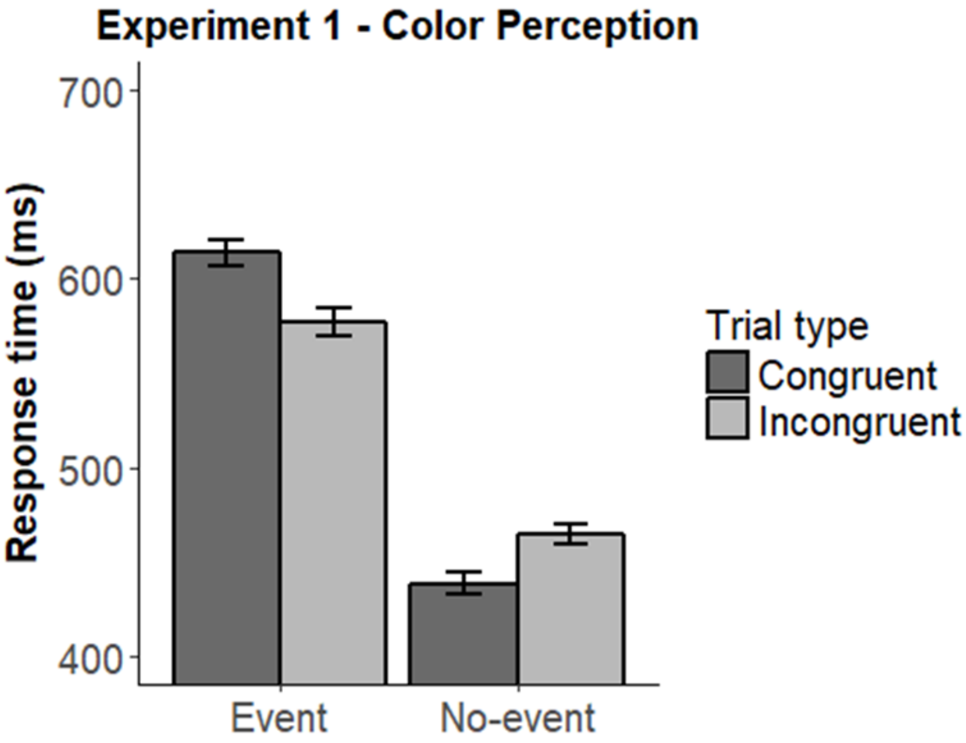

Figure 2. Mean response times for congruent and incongruent trials for the event and no-event conditions of Experiment 1. Error bars represent the standard error of the mean corrected for between-subject variability (Cousineau, 2005; Morey, 2008).

Table 1. Mean error percentages (%) across experiments.

Experiment 1

	Congruent	Incongruent
Event	6.9	5.7
No-event	5.0	6.4

Experiment 2

	Congruent	Incongruent
Event	10.2	6.9
No-event	7.4	5.9

Experiment 3

	Congruent	Incongruent	Catch-trials
Event	4.0	4.1	2.8
No-event	0.8	1.2	0.9

Experiment 4

	Congruent	Incongruent
Event	9.6	7.8
No-event	4.3	4.5

Experiment 5

	Congruent	Incongruent
Event	8.2	6.0
No-event	9.5	8.1

The analysis of RTs revealed a significant interaction between trial type and block, $F(1,19) = 23.6$, $p < .001$, $\eta^2_p = .55$. We explored this interaction further by examining the effects of trial type for each block separately. In the no-event block, responses were faster for congruent trials (439 ms) than incongruent trials (465 ms), $F(1,19) = 10.4$, $p = .005$, $d = .42$.[11] In contrast, in the event block, responses were faster for incongruent trials (577 ms) than congruent trials (614 ms), $F(1,19) = 13.4$, $p = .002$, $d = .33$.

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[11] All Cohen's *d* values reported in this manuscript were based on aggregate measures of performance in each condition for each participant (i.e., mean RTs, error rates) rather than on individual trial level measures of performance (i.e., RT or accuracy for individual trials). Otherwise, Cohen's *d* was computed using the classic method proposed by Cohen (1988); that is, the difference between means of two conditions divided by the pooled standard deviation for the two conditions.

The analysis of error rates revealed a significant effect of block, $F(1,19) = 13.0$, $p = .002$, $\eta^2_p = .41$, with more errors in the event block than the no-event block. There were no other significant effects in this analysis.

Discussion

The purpose of this experiment was to examine whether the repetition effect in a simple color discrimination task would reverse qualitatively with presentation of an intervening event between targets, as reported by Spadaro et al. (2012). Indeed, a facilitation effect was observed in the no-event condition, and an inhibition effect was observed in the event condition.

Experiments 2

In Experiment 2 we explored whether imagined colors can also produce the facilitation and inhibition effects. The experimental design was modified such that participants imagined the first target color in a trial, while the second target remained a perceptual color. Two groups of participants performed this task, one with an intervening event in the interval between targets (event group) and the other without an intervening event (no-event group). If imagined representations influence the same processes as underlie perception, we should find an inhibition effect for the event group and a facilitation effect for the no-event group.

Method

Participants. Forty undergraduates at McMaster University took part in Experiment 2 in exchange for course credit (35 female, $M_{\text{age}} = 18.8$ years). Twenty participants were assigned to each of the event and no-event groups.[12] All participants reported normal or corrected-to-normal vision.

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[12] The effect size used for the power analyses relevant to all following experiments in this manuscript was estimated from the data of Experiment 1. Although the event/no-event variable was manipulated within-subjects in Experiment 1 and between-subjects in all following experiments, a series of simulations we conducted showed that effect sizes and power for the interaction of primary interest in our study (event/no-event x trial type) are in most

Apparatus and stimuli. Apparatus and stimuli were identical to those used in Experiment 1.

Procedure. Experiment 2 was similar to Experiment 1 with the exception that the first target in a trial was no longer a perceptual color. Instead, participants were shown a white-outlined box containing either an 'R' or 'G'. Participants were instructed to imagine the color 'red' when the 'R' was displayed and 'green' when the 'G' was displayed. These two letters occurred with equal likelihood. When participants decided that they had completed the imagery task they pressed the key ('z' or 'm') corresponding to the color. The rest of the trial was identical to Experiment 1.

The event and no-event conditions were completed by separate groups of participants. In each of the event and no-event groups, participants performed 15 practice trials followed by a block of 200 experimental trials. At the end of the experiment, participants estimated the percentage of trials in which they implemented the imagery instruction.

Results

Exclusion of RTs less than 200 ms or greater than 2000 ms removed 2.4% and 1.4% of observations from the event and no-event groups, respectively. The remaining correct RTs were then submitted to the Van Selst and Jolicoeur (1994) outlier procedure, which removed a further 2.3% of observations from the event group and 3.2% of observations from the no-event group.

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cases comparable in a within-subject design with 20 participants and a between-subject design with 20 participants per group. In particular, consider that between-subject variability in overall RTs, which can contribute to the error term for some effects involving between-subject factors, does not contribute to the error term for the interaction of primary interest here. Rather, it is variability across participants in the difference between congruent and incongruent trials that serves as the major contributor to this error term. In any case, our power analyses indicated that a sample size of 20 participants per group would be sufficient to detect both the interaction (event/no-event x trial type) and simple main effects (trial type) of interest with power greater than .80. Further, we rationalized that any negative change in effect size in Experiments 2-5 relative to Experiment 1 caused by our measure of an imagery congruency effect rather than a perceptual repetition effect (Cochrane, Nwabuike, Thomson, & Milliken, 2018) would be counteracted by a positive change in effect size caused by an increase in number of observations per condition from 75 (Experiment 1) to 100 (Experiments 2-5).

Mean RTs computed from the remaining observations, and corresponding error rates, were submitted to mixed factor ANOVAs that treated trial type (congruent/incongruent) as a within subject factor and group (event/no-event) as a between subjects factor. The terms "congruent" and "incongruent" now referred to whether the imagined and the perceptual color matched or mismatched across targets within a trial. Mean RTs are displayed in Figure 3 and error percentages are displayed in Table 1.

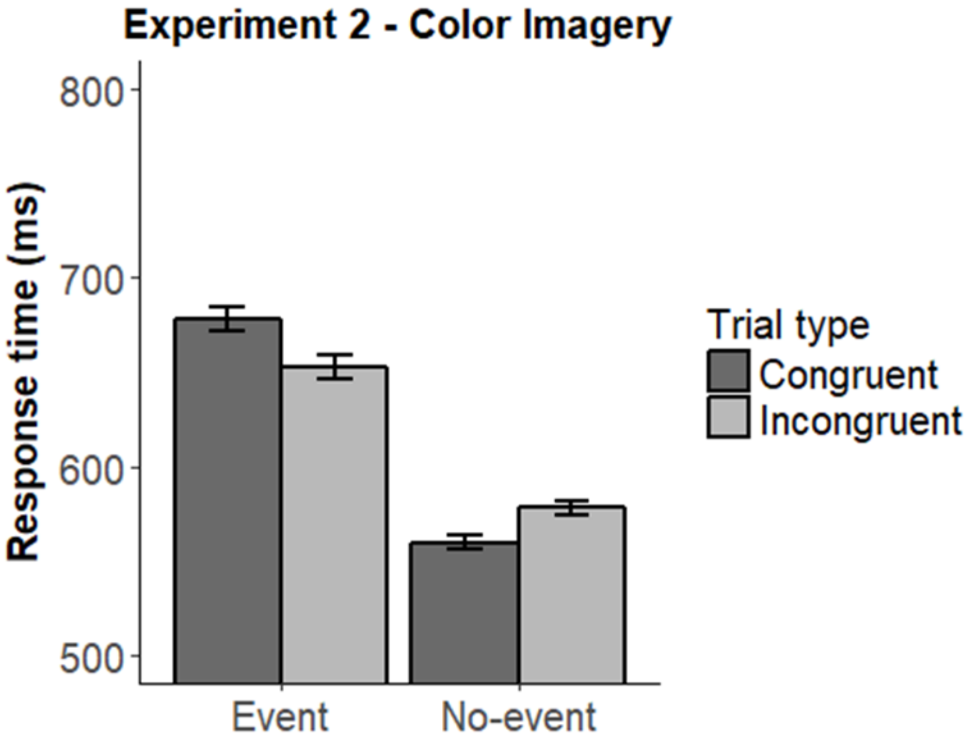

Figure 3. Mean response times for congruent and incongruent trials for the event and no-event groups of Experiment 2. Error bars represent the standard error of the mean corrected for between-subject variability (Cousineau, 2005; Morey, 2008).

The analysis of RTs revealed a significant interaction between trial type and group, $F(1,38) = 16.9$, $p < .001$, $\eta^2_p = .47$. Again, we explored this interaction further by examining effects of trial type for each group separately. In the no-event group, responses were faster for congruent trials (560 ms) than incongruent trials (578 ms), *F*(1,19) = 12.2, *p* = .003, *d* = .12. In contrast, in the event group, responses were faster for incongruent trials (652 ms) than congruent trials (678 ms), *F*(1,19) = 7.48, *p* = .01, *d* = .16.

The analysis of error rates revealed a significant main effect of trial type, *F*(1,38) = 9.80, *p* = .003, η^2_p = .34, reflecting more errors for congruent (9.0%) than incongruent (6.4%) trials. Although not significant, the direction of the interaction between group and trial type was generally consistent with the pattern of RTs (see Table 1), which mitigates a speed-accuracy trade-off interpretation of the RT pattern. No other significant effects were observed in this analysis. Mean post-experiment estimates of imagery use were 59.9% and 41.9% for the no-event and event groups, respectively.

Discussion

The purpose of Experiment 2 was to explore whether imagery could produce the facilitation and inhibition effects observed in Experiment 1. The analyses revealed that responses were faster when the target color was congruent with color imagery when the intervening event was absent, and faster when the target color was incongruent with color imagery when the intervening event was present. These results demonstrate for the first time that color imagery can produce facilitation and inhibition effects like those reported with perceptual colors (Spadaro et al. 2012).

Experiment 3

The purpose of Experiment 3 was to evaluate whether the imagery-based facilitation and inhibition effects observed with a discrimination task in Experiment 2 generalize to a detection task. Participants imagined the color ‘red’ or ‘green’ in response to an ‘R’ or ’G’, then detected the onset of a following perceptual color target.

Method

Participants. Forty undergraduates at McMaster University each took part in Experiment 3 in exchange for course credit (35 female, M_{age} = 19.0 years). Twenty participants were assigned to each of the event and no-event groups. All participants reported normal or corrected-to-normal vision.

Apparatus and stimuli. Apparatus and stimuli were identical to those used in Experiment 2.

Procedure. The procedure was identical to Experiment 2 with the following exceptions. Participants again generated color imagery in response to the letter 'R' or 'G', and then indicated that they had completed the imagery task by pressing the *spacebar*. The imagery component of the trial was then followed by a fixed blank interval of 2000 ms. In the event group, the purple/yellow square then appeared for 1000 ms. Participants made a color naming response to this intervening event, which was then followed by a blank screen for a variable interval of 50-1000 ms before onset of the perceptual target. In the no-event group, a blank screen was displayed in place of the intervening event, resulting in a variable blank interval of 50-2000 ms prior to onset of the perceptual target. Together, these constraints produced an intertrial interval that ranged from 2050-4000 ms in both groups. Upon onset of the perceptual color target, participants recorded their detection responses by pressing the *spacebar*.

On 20% of trials the perceptual target did not appear (catch trials), and participants had to withhold a response. If a response was made on catch trials, or if no response was made to the perceptual target within 2000 ms, the word 'incorrect' was centrally displayed on screen.

Results

Given that participants made detection rather than discrimination responses, RTs less than 150 ms or greater than 1250 ms were excluded from further analyses. This procedure removed 0.2% and 1.1% of observations from the analyses of the event and no-event groups, respectively. The same additional outlier procedure as in prior experiments then removed 2.3% and 2.4% of observations from the analyses of the event and no-event groups, respectively (Van Selst & Jolicoeur, 1994). Mean RTs were submitted to mixed factor ANOVAs that treated trial type (congruent/incongruent) as a within subject factor and group (event/no-event) as a between subjects factor. Mean RTs are displayed in Figure 4 and error percentages are displayed in Table 1.

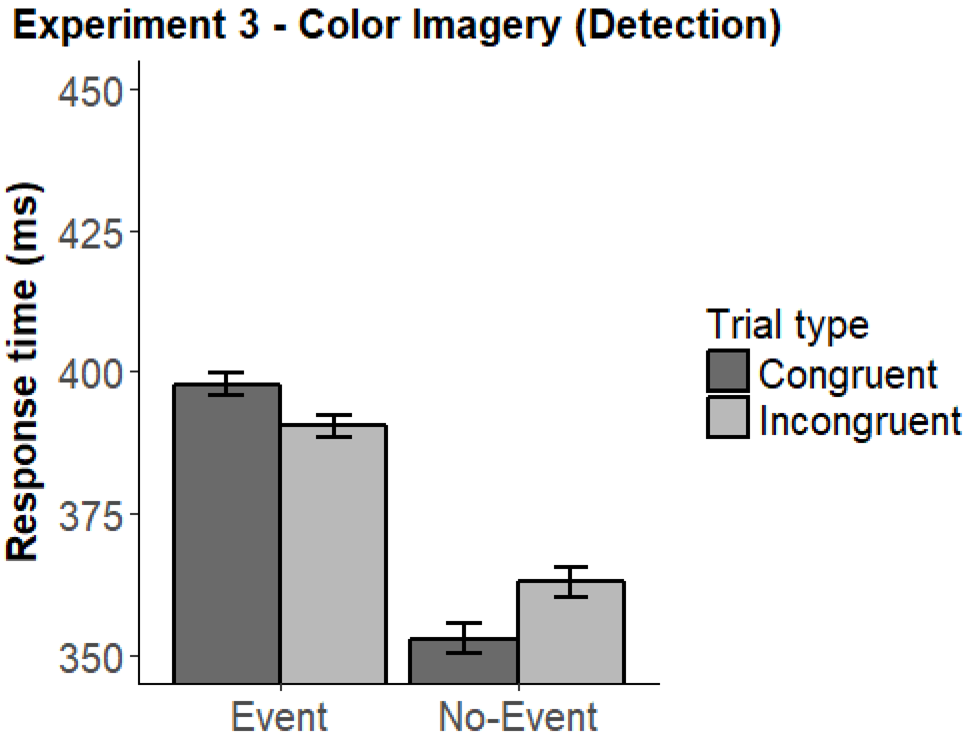

Figure 4. Mean response times for congruent and incongruent trials for the event and no-event groups of Experiment 3. Error bars represent the standard error of the mean corrected for between-subject variability (Cousineau, 2005; Morey, 2008).

The analysis of RTs again revealed a significant interaction between trial type and group, $F(1,38) = 10.3$, $p = .003$, $\eta^2_p = .21$. In the no-event group, responses were faster for congruent trials (353 ms) than incongruent trials (363 ms), $F(1,19) = 5.56$, $p = .03$, $d = .12$. In the event group, responses were faster for incongruent trials (390 ms) than congruent trials (398 ms), $F(1,19) = 4.79$, $p = .04$, $d = .08$.

A corresponding analysis of errors (i.e., misses) revealed a significant main effect of group, $F(1,38) = 4.64$, $p = .04$, $\eta^2_p = .11$, with higher error rates for the event group (4.1%) than the no-event group (1.0%). A separate one-way analysis of catch trial errors that treated group as a factor revealed a non-significant effect ($p = .13$). No other effects in the analysis of errors were significant. Mean post-experiment estimates of imagery use were 60.0% and 45.9% for the no-event and event groups, respectively.

Discussion

The purpose of Experiment 3 was to evaluate whether the imagery-based facilitation and inhibition effects observed in Experiment 2 generalize to detection tasks. When an intervening event was presented between targets, detection of congruent targets was slower than detection of incongruent targets. Conversely, when an intervening event was not presented between targets, detection of congruent targets was faster than detection of incongruent targets. These results demonstrate that the imagery-based facilitation and inhibition effects reported in Experiment 2 do generalize to detection tasks.

Experiments 4

So far, we have demonstrated that both color perception and color imagery are sufficient to produce the facilitation and inhibition effects. However, these results do not demonstrate that color perception and color imagery are necessary to produce these effects. Conceptual representations activated in response to both the color perception and imagery tasks could in principle have caused both effects. We conducted Experiment 4 to test whether conceptual representations of color can produce the facilitation and inhibition effects. Here, the 'R' and 'G' letters were presented without the explicit instruction to generate color imagery. Instead, it was made clear to participants that these letter targets represented their corresponding color. If visual representations of color are necessary to produce the facilitation and inhibition effects, then these effects should not occur in this experiment.[13]

Method

Participants. Forty undergraduates at McMaster University each took part in Experiment 4 in exchange for course credit (36 female, $M_{\text{age}} = 18.7$ years). Twenty participants were assigned to each of the event and no-event groups. All participants reported normal or corrected-to-normal vision.

Apparatus and stimuli. Apparatus and stimuli were identical to those of previous experiments.

Procedure. The procedure was identical to that of Experiment 2 with the exception that participants were not instructed to generate color imagery. Instead, participants were explicitly told that the letter 'R' represented 'red' and the letter 'G' represented 'green', and that they were required to respond to these letters with a key-press that followed the same stimulus-response mapping as for the following color target.

Results

Exclusion of RTs less than 200 ms or greater than 2000 ms removed 3.2% of observations in the event group and 2.6% of observations in no-event group from further

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[13] That is, unless visual representations are activated involuntarily without the imagery instruction (see Cochrane & Milliken, 2019).

analysis. The same additional outlier procedure as in prior experiments removed 1.3% and 3.4% of observations from analysis in the event and no-event groups, respectively. Mean RTs and corresponding error percentages were then submitted to mixed factor ANOVAs that treated trial type (congruent/incongruent) as a within subject factor and group (event/no-event) as a between subjects factor. Mean RTs are displayed in Figure 5 and error percentages are displayed in Table 1.

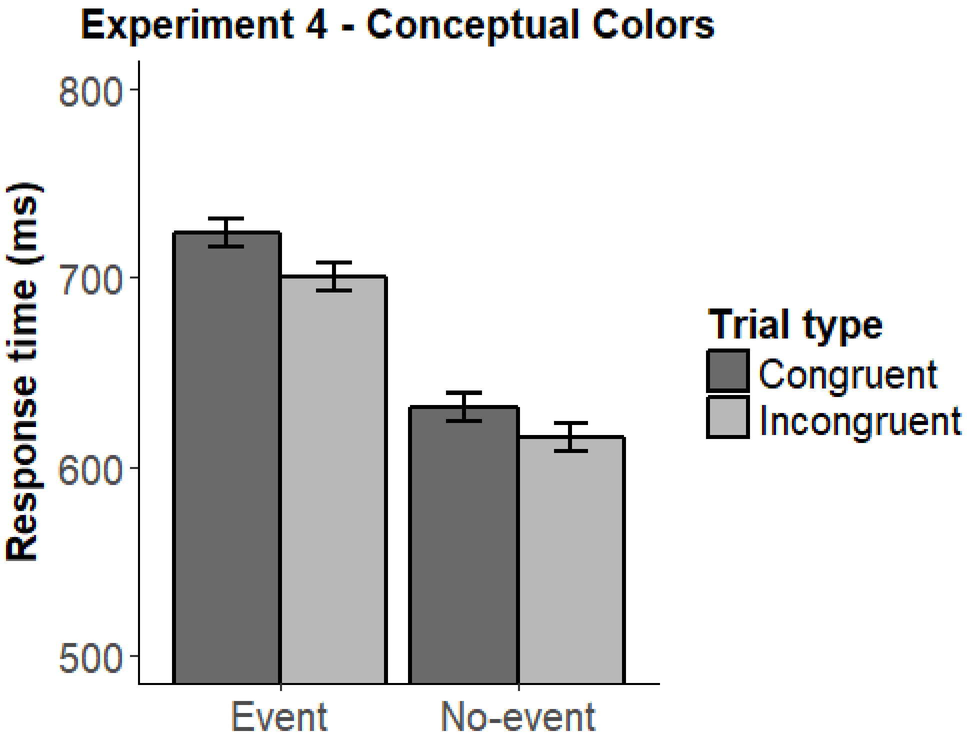

Figure 5. Mean response times for congruent and incongruent trials for the event and no-event groups of Experiment 4. Error bars represent the standard error of the mean corrected for between-subject variability (Cousineau, 2005; Morey, 2008).

The analysis of RTs revealed a significant main effect of trial type, $F(1,38) = 6.53$, $p = .01$, $\eta^2_p = .15$, reflecting faster responses for incongruent trials (658 ms) than congruent trials (677 ms). The main effect of group approached significance ($p = .08$), with slower responses for the event group than the no-event group. Importantly, the interaction between trial type and group was not significant (p = .62). Given our a priori interest in performance of each of the two groups, we examined effects of trial type for each group separately. In the no-event group, RTs for congruent trials (631 ms) did not differ significantly from those for incongruent trials (616 ms; p = .16). Note that this pattern of results contrasts with the facilitation effects reported for the no-event groups of prior experiments. In the event group, responses were faster for incongruent trials (700 ms) than congruent trials (723 ms), F (1,19) = 4.69, p = .04, d = .11.

The analysis of error rates revealed a significant main effect of group, F(1,38) = 6.33, p = .02, η^2_p = .14, with higher error rates in the event group (8.7%) than the no-event group (4.4%). All other effects in the analysis of error rates were not significant.

Discussion

The purpose of Experiment 4 was to assess whether color perception/imagery for the first of two targets is necessary to observe the facilitation and inhibition effects reported in Experiments 1-3. When color targets were preceded by letter targets that represented those colors, an inhibition effect was observed in the event group but there was no sign of a facilitation effect in the no-event group. These results imply that the color imagery instruction was critical to the facilitation effect in the no-event groups of Experiments 2 and 3, which fits with the idea that the facilitation effect involves representations that are visual in nature. A second implication of these results is that the color imagery instruction was not critical to the inhibition effect. As in all prior experiments, an inhibition effect was observed for the event group. This issue was examined further in Experiment 5.

Experiments 5

There are two possible sources of the inhibition effect observed in Experiment 4. First, the inhibition effect may be related to the overlap in conceptual representations for the first and second target on each trial (the letter ‘R’ represented ‘red’, which was conceptually related to a following red target). Second, the inhibition effect may be related to the overlap in response representations for the first and second target on each trial (the letter ‘R’ required a right key-press, an identical response to that required for the following red target). If the inhibition effect reported in Experiment 4 was related to response representations, the inhibition effect should also be present if participants respond to targets that are conceptually unrelated to following target colors. To test this idea, the first target on each trial was either an ‘X’ or ‘O’, and the second target was a perceptual color. Importantly, these two letter and color targets were mapped to the same response keys.

Method

Participants. Forty undergraduates at McMaster University each took part in Experiment 5 in exchange for course credit (28 female, M_{age} = 18.6 years). Twenty participants were assigned to each of the event and no-event groups. All participants reported normal or corrected-to-normal vision.

Apparatus and stimuli. Apparatus and stimuli were identical to those of Experiment 4.

Procedure. The procedure was identical to that of Experiment 4 with the exception that the first target in a trial was either an ‘X’ or ‘O’. Participants responded to these letter targets using the ‘z’ and ‘m’ keys, the same keys used to respond to the following perceptual target. Response keys of these two letter and color targets were counterbalanced across participants.

Results

Exclusion of RTs less than 200 ms or greater than 2000 ms removed 5.8% of observations in the event group and 3.0% of observations in the no-event group from further analysis. The same additional outlier procedure as in prior experiments removed 2.3% of observations in the event group and 3.7% of observations in the no-event group from further analysis. Mean RTs and corresponding error rates were then submitted to mixed factor ANOVAs that treated trial type (congruent/incongruent) as a within subject factor and group (event/no-event) as a between subjects factor. Given that the first and second targets were now conceptually unrelated, trial type (congruent/incongruent) reflected whether key-press responses matched or mismatched across targets in a trial. Mean RTs are displayed in Figure 6 and error percentages are displayed in Table 1.

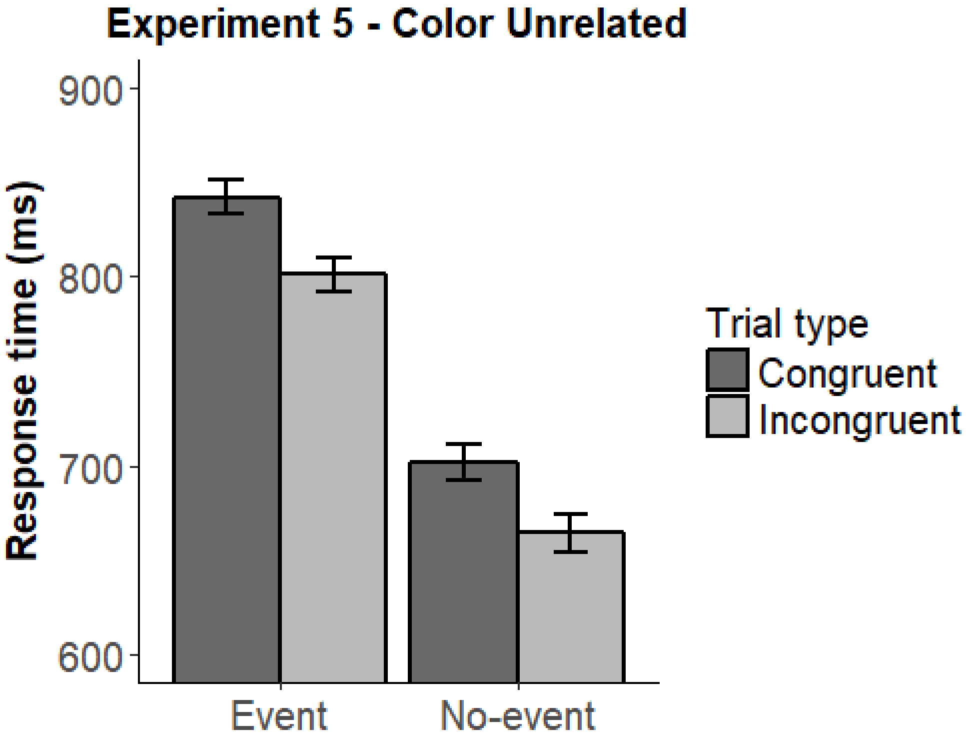

Figure 6. Mean response times for congruent and incongruent trials for the event and no-event groups of Experiment 5. Error bars represent the standard error of the mean corrected for between-subject variability (Cousineau, 2005; Morey, 2008).

The analysis of RTs revealed a significant main effect of trial type, $F(1,38) = 16.6$, $p < .001$, $\eta^2_p = .30$, reflecting faster responses for incongruent trials (733 ms) than congruent trials (772 ms). The main effect of group was also significant, $F(1,38) = 5.96$, $p = .02$, $\eta^2_p = .14$, reflecting faster responses in the no-event group (683 ms) than the event group (822 ms). As in Experiment 4, the interaction between trial type and group was not significant ($p = .86$). Given a priori interest in the performance of each group, we examined the effects of trial type for each group separately. In the no-event group, responses were faster for incongruent trials (664 ms) than congruent trials (702 ms), $F(1,19) = 7.01$, $p = .02$, $d = .24$. In the event group, responses were also faster for incongruent trials (801 ms) than congruent trials (842 ms), $F(1,19) = 9.91$, $p = .005$, $d = .20$. In other words, an inhibition effect was observed for both groups.

The analysis of error rates revealed a significant main effect of trial type, $F(1,38) = 10.4$, $p = .002$, $\eta^2_p = .21$, reflecting higher error rates for congruent trials (8.9%) than incongruent trials (7.1%). All other effects in the analysis of error rates were not significant.

Discussion

The purpose of Experiments 5 was to examine whether conceptually unrelated targets that shared response keys would produce the inhibition effect. In both the event and no-event groups, perceptual color discrimination was slow for response repetitions relative to response alternations across the first and second target. This result suggests that the inhibition effect reported in Experiment 4 was not caused by the conceptual relatedness of the first and second targets. Instead, the inhibition effect in both Experiments 4 and 5 appears to be related to performing the same key-press response across target displays.

General Discussion

Over the course of five experiments we explored the representational basis of non-spatial facilitation and inhibition effects. We used a procedure that varied the representational overlap of the first and second targets by fixing the second target to be a perceptual color, and then varying the nature and processing of the first target. In Experiment 1, the first and second targets were both perceptual colors. A facilitation effect was observed when there was no intervening event between targets, and an inhibition effect was observed when there was an intervening event between targets. In Experiment 2, the first target was a letter (‘R’ or ‘G’) that cued participants to imagine red or green, and the results were identical to those in Experiment 1; a facilitation effect without the intervening event, and an inhibition effect with the intervening event. In Experiment 3, the same method was used as in Experiment 2, but with participants required to detect onset of the second target rather than to discriminate its color. The results were identical; a facilitation effect without the intervening event and an inhibition effect with the intervening event. In Experiment 4, the first target was again the letter ‘R’ or ‘G’, participants were informed that the letters represented the colors ‘red’ and ‘green’, respectively, and they were to discriminate between the two possible targets with a button-press. However, they were not asked to engage in color imagery in this experiment. The results of this experiment differed in an important way from those of Experiments 1-3; although there was again an inhibition effect with the intervening event, there was now a non-significant inhibition effect, rather than a facilitation effect, without the intervening event. In Experiment 5, participants discriminated between a first target ‘X’ or ‘O’ with one of two button presses, and then discriminated between two possible color targets, as in prior experiments, with the same pair of button presses. In this case, an inhibition effect (i.e., slower response repetitions than responses alternations) was observed both with and without the intervening event.

Together, these results point to two important observations. First, a facilitation effect in trial-to-trial repetition effects can be produced by visual imagery of the first target. This result was observed in the no-event groups of Experiments 2 and 3, and paralleled the facilitation effect observed for the no-event condition in Experiment 1. No such facilitation was observed for the no-event groups of Experiments 4 and 5, suggesting that the facilitation effect has a perceptual basis. Second, when an intervening event was presented between targets, an inhibition effect was observed in all five experiments. In addition, an inhibition effect was observed in the no-event condition of Experiments 5. These results suggest that non-spatial facilitation and inhibition effects have different underlying bases. In the following sections we discuss the theoretical implications of this pattern of results in more detail.

A Theory of Non-Spatial Facilitation and Inhibition Effects

One theory for the results reported here assumes that response repetition and perceptual repetition produce opposite influences on performance. By this view, the inhibition effect observed in the present study is driven by response inhibition that slows responding for recently made motor responses. This process is always operative regardless of the visual aspects of the stimulus, influencing the congruent trials in all experiments presented here. In contrast, the facilitation effect is driven by a process that speeds responding to a target stimulus that is preceded by a stimulus that is visually similar (Beller, 1971; Posner & Mitchell, 1967; Rosch, 1975). Further, this process only influences performance in the absence of an intervening event between targets. The idea here is that the facilitation effects observed for color imagery and perception in the no-event groups were due to a process that prevailed over the process responsible for the inhibition effect. When there was either insufficient representational overlap across targets or an event intervening between target displays, the processes driving the facilitation effect were not operative and the process responsible for the inhibition effect dominated.

However, a limitation of this theory is that it fails to explain the findings of Experiment 3. Here, participants responded to the color imagery cue by pressing the *spacebar*, then responded to the onset of perceptual color targets also by pressing the *spacebar*. Note that response inhibition would not produce an inhibition effect in this case as responses were identical for congruent and incongruent targets. Yet, an inhibition effect was observed in the event group of Experiment 3. This result suggests that a theory that incorporates some mechanism other than response inhibition is required to explain the inhibition effect reported here.

Event-mediated habituation. A theory that can account for the inhibition effect in Experiment 3 is similar to that proposed by Spadaro et al. (2012). They propose that the intervening event eliminates the contribution from processes responsible for the facilitation effect, while revealing a process that produces habituation for visual features of recently observed targets. When these visual features are repeated following the intervening event, they are less easily detected than the relatively novel targets (see Lupiáñez, 2010).[14]

Event-mediated habituation can explain all the inhibition effects observed in Experiments 1-3. When the first target in each display was either a perceptual color (Experiment 1) or an imagined color (Experiments 2-3) the facilitation and inhibition effects were modulated by the intervening event. When the intervening event was present, the inhibition effect was observed – that is, responses were faster when targets were incongruent across displays than when they were congruent. When the intervening event was removed, responses were faster when targets were congruent across trials than when they were incongruent, suggesting that the processes underlying the facilitation effect predominated.

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[14] It is worth noting that the two-process account proposed by Spadaro et al. (2012) attributed facilitation effects to retrieval of an S-R binding (e.g., blue-right) for a first target that is compatible with that required to respond to a second target. Intervening events are presumed to disrupt the retrieval of the S-R binding for a preceding target, thus eliminating the facilitation effect and revealing an opposing influence that produces the inhibition effect. Recent data from our lab suggest that this account of facilitation effects is likely to be incorrect (Lorentz & Milliken, 2018). In this study, intervening events were found not to impact the influence of S-R bindings on trial-to-trial repetition effects. Nonetheless, in our view, the general idea that intervening events disrupt a process that opposes the process responsible for inhibition effects remains sensible.

At the same time, a limitation of the event-mediated habituation proposal is that it cannot account for the inhibition effects observed in Experiments 4 and 5. In Experiment 5, for example, the first target (‘X’ or ‘O’) was perceptually different from the second target (red or green) on both congruent and incongruent trials, and therefore could not lead to a habituation effect that has a perceptual basis. For the ‘conceptual’ color first targets in Experiment 4 (i.e., the letter ‘R’ or ‘G’), we suspect that this was also the case – that is, that conceptual color targets did not evoke perceptual representations that would produce a habituation effect. We conclude that some other theory is required to account for the findings of Experiments 4 and 5.

Theory of event coding (TEC). TEC proposes that when an action is made in response to a stimulus, a transient memory trace is established binding the stimulus features and the associated response, termed an event file (Hommel, 1998; Hommel, 2004; Hommel et al., 2001). When a new stimulus shares one or more features with a preceding stimulus, the event file is automatically retrieved. If the stimulus-response (S-R) bindings of the new stimulus match perfectly with those of the event file, then performance is relatively efficient. When a new stimulus contains none of the S-R features in the event file binding, performance is also relatively efficient. However, when the new stimulus matches the event file binding on one feature, but mismatches on one or more other features, a relatively slow updating of the memory trace occurs, which slows responding. In summary, TEC assumes that slowed responding occurs for these ‘partial match’ trials, relative to complete S-R binding overlap and nonoverlap trials.

We suspect that this updating process was responsible for the inhibition effects reported in Experiments 4 and 5. When the first target was an ‘X’ or ‘O’ (Experiment 4) or a conceptual color (‘R’ or ‘G’), and the second target was a perceptual color, two types of S-R bindings were formed. One type of S-R binding was a complete mismatch, formed when participants made different key-press responses to different targets across displays (e.g., *left*-X, *right*-green). As noted above, these complete mismatches should produce relatively efficient responding. The second type of S-R binding was a partial match, formed when participants made the same key-press response to different targets across displays (e.g., *left*-X, *left*-red). According to TEC, these partial match trials result in relatively slow responding. This is precisely what was observed – responses were slower for 'congruent trials' (e.g., partial matches) than for 'incongruent trials' (e.g., complete mismatches). Overall, this pattern of results observed in Experiments 4 and 5 is explained perfectly by TEC.

Notably, in Experiments 1-3 the inhibition effect cannot be explained by TEC. In these experiments the first target was either a perceptual or imagined color, leading to two types of S-R bindings. One type of S-R binding was a complete match, formed when participants responded to the same colored target with the same key-press response across target displays (e.g., *left*-red, *left*-red). The second type of S-R binding was a complete mismatch, formed when participants responded to different colored targets with different key-press responses across target displays (e.g., *left*-red, *right*-green). According to TEC, there should be no difference in responding across these complete match and mismatch trials since neither trial type requires the slow updating that occurs on partial match trials. For this reason, we proposed that event-mediated habituation accounts for the inhibition effects in these experiments. In summary, we propose that two different processes produce the inhibition effects reported across the five experiments reported here – an event-mediated habituation process when the visual features were shared across target displays, and a memory trace updating process when visual features were not shared across target displays.

Conclusion

The primary finding here was that color imagery produced non-spatial facilitation and inhibition effects like that produced by perceptual color. Importantly, conceptual colors did not produce this pattern of results, instead producing a pattern of results similar to non-color targets. This result strongly suggests that color imagery influences brain networks associated with the visual properties of color perception. Further, it appears that non-spatial inhibition effects have more than one cause – event-mediated habituation processes offer the best explanation of inhibition effects when visual features were shared across targets displays, whereas memory updating processes as identified in TEC offer the best explanation of inhibition effects when visual feature were not shared across target displays.

Chapter 6: General Discussion

The primary objective of this thesis was to examine whether color imagery produced effects that were similar to those produced by perceptual colored stimuli. The additional goal here was to evaluate whether this investigation could lead to a better understanding of the processes underlying visual perception. Here, several perceptual effects were investigated to see whether they could be produced with color imagery. In Chapter 2, the influence of color imagery on the Priming of Pop-out effect was evaluated. In Chapter 3, the limits of the imagery congruency effect were demonstrated by varying a number of experimental parameters. In Chapter 4, binding involving imagery and responses was examined to evaluate partial repetition costs. In Chapter 5, color imagery was used to produce the non-spatial facilitation and inhibition effects. In the following sections, the findings of each empirical chapter are summarized and several theoretical issues are discussed.

Summary of Empirical Chapters

Chapter 2. The primary goal of Chapter 2 was to examine the influence of color imagery on the Priming of Pop-out (PoP) effect. In Experiments 1a and 2a, the typical PoP effect was observed in the control group using the trial pair procedure. In the visual imagery groups of Experiments 1a, 1b, and 2a, participants were instructed to imagine the ‘opposite’ color during the interval between trials in each trial pair, which showed a reversal of the PoP effect – faster response when the target color switched across trials than when it repeated. When participants were instructed to verbalize the ‘opposite’ color in Experiments 1b and 2b, the PoP effect was not reversed.

In Experiment 3, we examined the influence of visual imagery under conditions in which the color pairs of the target and distractors either remained the same across trial pairs (the imagine-opposite condition) or changed between trials in each trial pair (the imagine-new condition). A feature of the imagine-new condition was that the influence of congruency between visual imagery and search target color could be measured without any possible influence of the PoP effect pushing in the opposite direction. The congruency effect differed between the imagine-opposite and imagine-new conditions, with the advantage for switch over repeat trials in the imagine-opposite condition being smaller than the advantage for congruent over incongruent trials in the imagine-new condition. The conservative interpretation of this result is that the target color repetition effect for the imagine-opposite condition reflected a mix of two separate processes; a PoP effect that speeds performance for repeats relative to switches, and a visual imagery effect that speeds performance for switches relative to repeats. However, analysis of the trial pairs where participants reported strong color imagery offers support for an alternative interpretation – that visual imagery influenced the representations driving the PoP effect. Specifically, when participants reported that their color imagery was ‘vivid like perception’, the magnitude of congruency effects were virtually identical across the imagine-opposite and imagine-new conditions. This issue will be explored further at a later point in the General Discussion.

Chapter 3. Wantz, Borst, Mast, and Lobmaier (2015) found that when color imagery was congruent with perceptual colored targets it speeded responding. Chapter 3 scrutinized the method used by Wantz et al. and offered an alternative method that allowed for a stronger inference that color imagery can influence performance in a subsequent perceptual task.

In Experiment 1, the key results of Wantz et al. (2015) was replicated. In Experiment 2, a two-color variant of the same task was used that ensured that imagery cues did not predict following target colors, which reduced the size of the congruency effect substantially. In

Experiment 3, the response dimension was made orthogonal to the color dimension, and the congruency effect disappeared entirely. In Experiments 4-6, the methodological constraints imposed in the earlier experiments were maintained and it was evaluated whether color imagery could aid a subsequent visual search task. In Experiments 4a and 4b, when a lone target square was presented, the congruency effect was not observed. In Experiments 5a and 5b, a singleton color target square was presented with three homogenously colored distractor squares, and a significant congruency effect was observed. In Experiments 6a and 6b, this congruency effect was again observed when participants completed an articulatory suppression task during color imagery. Overall, the results demonstrate that color imagery can influence performance in a following perceptual task, but that it only appears to have profound influence in visual search.

Chapter 4. The goal of Chapter 4 was to evaluate whether color imagery could be bound to responses in order to produce stimulus-response event file binding effects. In Experiment 1, the event file binding effect was observed with perceptual stimuli - when an arbitrary keypress was made in response to a perceptual color stimulus, performance was efficient in a following color discrimination task when the stimulus and response features completely matched or mismatched across these tasks. When stimulus and response features partially matched performance was hindered, constituting the partial repetition cost. It was also observed that when arbitrary responses were made following color imagery based on a letter cue (‘R’ or ’G’), the same pattern of results was observed. In Experiment 2, when the same experimental procedures were used as in the imagery experiment except that participants were not instructed to generate color imagery, the event file binding effect was not observed.

In Experiment 3, when participants’ verbalized the color instead of generating color imagery, the event file pattern of results was also observed. In Experiment 4, the generation of verbal representations was controlled by requiring participants to generate color imagery while engaging in articulatory suppression, and the event file binding effects were observed nonetheless. Post-hoc analysis suggested that the magnitude of the event file binding effects in the imagery condition was modulated by the self-reported vividness of color imagery, supporting the notion that color imagery can be independently responsible for these effects. Overall, it is proposed that both verbal and imagined representations can produce event file binding effects.

Chapter 5. In Chapter 5 the non-spatial facilitation and inhibition effects were explored. A target-to-target discrimination task was used where the second target in a pair of trials was always a perceptual color and the representational basis of the first target varied across experiments. In Experiment 1, when the first and second targets were both perceptual colors, a facilitation effect was observed when there was no intervening event between targets, and an inhibition effect was observed when there was an intervening event between targets. In Experiment 2, when the first target was a letter that cued participants to imagine a color, the results were identical to those in Experiment 1. In Experiment 3, the same method was used as in Experiment 2, but with participants required to detect onset of the second target. Here, the results were once again identical. Experiment 4 was identical to Experiment 2 except that the participants were informed that the letter of the first target represented a color but were not given the explicit instruction to generate imagery. Here, there was an inhibition effect with the intervening event condition, and there was now a non-significant inhibition effect in the no-intervening event condition. In Experiment 5, participants discriminated between a first target ‘X’ or ‘O’ and then discriminated between two possible color targets, as in prior experiments. The results were that the inhibition effect was observed both with and without the intervening event.

Together, these results point to two important findings. First, a facilitation effect in trial-to-trial discrimination tasks can be produced by color imagery of the first target. This result was observed in the no-event groups of Experiments 2 and 3, and was similar to the facilitation effect observed for the no-event condition in Experiment 1. No such facilitation was observed for the no-event groups of Experiments 4 and 5, suggesting that the facilitation effect has a perceptual basis. Second, when an intervening event was presented between targets, an inhibition effect was observed in all five experiments. These results suggest that non-spatial facilitation and inhibition effects have different underlying basis. In summary, it was proposed that the facilitation effect is produced by a process that leads to efficient responding to a target when there is perceptual (i.e., color perception or color imagery) overlap across displays. The inhibition effect is produced by a more complex relationship between stimulus and response features; there is likely an event-mediated habituation-like process that occurs when an event intervenes between repeated stimuli in the same spatial location.

Theoretical Issues

Does color imagery influence the processes driving the PoP effect? This is a difficult question to answer. One concern is that the PoP effect is putatively caused by at least two processes (Becker, 2008b; Hillstrom, 2000; Huang, Holcombe, & Pashler, 2004; Kristjansson & Campana, 2010; Lamy, Yashar, & Ruderman, 2010). As noted by Lamy, Yashar and Ruderman (2010), the PoP effect is caused by two separate processes that may concurrently compose the behavioral effect: (i) an attentional process that speeds attention/eye-gaze to the target (see also, McPeek, Maljkovic, & Nakayama, 1999), and (ii) a response-related process that leads to efficient decision making (see also Goolsby & Suzuki, 2001).

It appears that the PoP effects reported in Chapter 2 were primarily produced by attentional processes. In experiments conducted but not included in the thesis, color imagery was cued prior to a singleton search task, while eye-movements were monitored (Cochrane, Wang, Milliken, & Sun, in-prep). The color imagery could either match the color of the target, the color of the distractors, or neither color in the search display. The analysis revealed that when color imagery matched the target in the singleton search task, participants were fast to respond compared to the other two conditions. Participants were slowest to respond when color imagery matched the distractors. Importantly, decomposition of overall response times revealed that the congruent color imagery effect was driven by fast localization of the target rather than by slow responding following target localization. Accordingly, it appears that color imagery most prominently affects the attentional processes guiding visual search.

In further work, whether color imagery and the PoP effect were guided by the same attentional process was investigated. In Chapter 2, the results were not entirely clear whether color imagery and the PoP effect affected the same process – the overall pattern in the data of Experiment 3 suggested that the processes guiding the PoP effect and color imagery were separate, while analyses that assessed only trials in which color imagery was reported to be strong suggested that color imagery and the PoP effect were guided by the same process. To address this issue we conducted a series of experiments that carefully evaluated whether the same processes were driving the imagery and the PoP effects (Cochrane, Ng, & Milliken, in-prep). Participants were cued to imagine either the same color or the opposite color of the target of a first singleton search trial in the temporal interval prior to a second singleton search trial. Following this pair of trials, participants reported the strength of their color imagery. If the processes driving color imagery and the PoP effect are separate, then the imagery congruency effect should be smaller when participants imagine a color that is opposite the previous target than when they imagine a color that is the same as the previous target. This prediction follows from the idea that processes guiding color imagery and the PoP effect should be working in opposition in the imagine-opposite condition (e.g., subtractive influence), and working in concert in the imagine-same condition (e.g., additive influence). The data revealed that when participants reported strong color imagery, there was no significant difference in the imagine-opposite and imagine-same conditions. Further experiments using repeated target sequences demonstrated that color imagery also eliminated the passive build-up of color priming, a feature of the PoP effect (Brascamp, Pels, & Kristjansson, 2011). Overall, it appears that color imagery does indeed impact the attentional processes producing the PoP effect here. An interpretation of this finding is that representations produced by color imagery and the PoP effect compete for the same priority map that functions to guide attention (for a similar interpretation see Belopolsky, 2015).

When are facilitation effects present in non-spatial tasks? In Chapter 3 (Experiment 3), participants were required to imagine a color based on a letter cue (‘R’ or ‘G’) in a central blank square displayed on the screen. Following a two-second temporal interval, participants indicated the side of the notch in a target square that was either congruent or incongruent with color imagery. This analysis failed to find a significant color congruency effect. In Chapter 5 (Experiment 3, no-event group), participants imagined a color based on a letter cue (‘R’ or ‘G’), pressing the *spacebar* once imagery was complete. Following a variable temporal interval, participants had to press the *spacebar* at the onset of targets that were either congruent or incongruent with color imagery. This analysis revealed a significant congruency effect such that participants were faster to detect the perceptual color patch when it was congruent with the preceding color imagery than when it was incongruent.

Given the similarity of these two experiments, it is puzzling why a significant imagery congruency effect was observed in one experiment and not the other. A seemingly subtle difference that may have had a profound impact relates to the nature of the tasks. The notch discrimination task used target stimuli that were dissimilar to the imagined representations, as the imagery instruction asked participants to imagine a solid color box. This was not true in the onset detection tasks; the imagined and perceptual representations were both solid colored boxes. This dissimilarity may have produced a partial match between the stimulus features, which hindered performance. Indeed, it has been demonstrated that partial match effects can be produced by irrelevant stimulus features of perceptual stimuli (Denkinger & Koutstaal, 2009; Frings & Rothermund, 2011; Treisman, 1992). Further, we have demonstrated that color imagery can be bound to task irrelevant spatial features (Cochrane, Uy, Milliken, & Sun, in-prep). Considering these findings, a sensible conclusion is that irrelevant shape features were included in these bindings.

Another possibility is that differences across the notch discrimination and onset detection tasks could have changed the degree to which participants engaged in the imagery task. It may have been that participants frequently generated color imagery prior to the onset detection task since it appeared to be sensible; while in the notch discrimination task, participants may have been more likely to abandon their imagery since it hindered performance by drawing their attention to aspects of the stimulus that were irrelevant to the task. Ultimately however, further research is necessary to resolve this issue.

When do verbal representations influence performance? Another inconsistent finding in this thesis concerns the influence of verbal representations on performance. In Experiments 1b and 2b of Chapter 2, participants completed singleton search trials that were presented in pairs. Similar to the imagery variant of this task, participants verbalized the opposite color of the singleton target from the first trial in a trial pair, during the temporal interval between the first and second trials in a trial pair. Both experiments showed that verbalized colors failed to produce a color congruency effect, suggesting that verbal representations had minimal influence on visual search performance.

Alternatively, Experiment 3 of Chapter 4 demonstrated that verbalization of color could produce stimulus response binding effects just like imagery and perception. Participants provided an arbitrary key-press response following the verbalization of a color based on a letter cue (‘R’ or ‘G’). Participants then performed a color discrimination task using the same response keys. The analysis revealed that performance was efficient when the verbalized color and arbitrary responses completely matched or mismatched those of the color discrimination task. When there was a partial match of either the verbalized color or response with that of the color discrimination task, performance was hindered. This finding suggests that verbal representations of color can contribute to event files that are ultimately retrieved upon presentation of perceptual colors.

It is proposed in the General Discussion of Chapter 4 that verbal representations produce event files with this property because verbal representations automatically evoke imagined representations. This proposal is aligned with theoretical frameworks in which perception and knowledge systems are inseparably linked (Barsalou, 2008; Varela, Thompson, & Rosch, 1991; Wilson, 2002). Furthermore, half of the participants in this experiment reported generating color imagery when performing the verbal variant of the task, making it difficult to determine whether the pattern of results was due to verbal representations independent of imagery. A possible distinction between verbal and imagined representations of color is the degree to which these representations are maintained across time. It may be that verbalized colors produce imagery, but only transiently, whereas the process of generating color imagery entails the maintenance of the color representations across time. If the visual search effects in Chapter 2 depended on the maintenance of the color representations across time, then this may explain why verbal representations failed to elicit such effects.

Another possibility is that singleton search and event file procedures are driven by different sets of processes that have different representational thresholds. It has been proposed that color imagery influences attentional processes that guide visual search. It has also been proposed elsewhere that verbal/semantic representations have little impact on these same attentional processes (Muller & Krummenacher, 2006; Theeuwes, Reimann; Mortier, 2006; Wolfe, Horowitz, Kenner, Hyle, & Vasan, 2004). Accordingly, it seems that these attentional processes may depend on representations that are of a perceptual nature (i.e., imagery) to be operative. These attentional processes then might be different from the stimulus-response binding processes that produce event file binding effects. Unlike the attentional processes, event files are affected by a wide variety of features, including color, shape, location, orientation, motion, associated responses, and task context (Hommel, 2004; 2009; 2019; Naber, Eijgermans, Herman, Bergman, & Hommel, 2016). Further, knowledge of response features may be sufficient to form event files (Hommel, 2009; Frings & Rothermund, 2013). Given that the knowledge of response features is sufficient to form event files, it seems sensible that verbal representations may be formed into event files in a similar manner.

Are imagery effects the same as perceptual effects – are they larger? One of the goals of this thesis was to investigate whether color imagery produced effects similar to color perception. It was indeed predicted that imagery and perception effects would be virtually identical. To our surprise, in many of the experiments here color imagery produced effects that were larger than the perceptual counterpart.

A first example of this pattern of results relates to the imagery effects in singleton search tasks (Chapter 2). Here, it was demonstrated that color imagery produced effects that were larger in magnitude than the original PoP effect. This issue was explored further in Cochrane, Wang, Milliken, and Sun (in-prep). Participants were shown a perceptual color patch prior to a singleton search task in which the oddball color was the target. Results from this task were compared to those from a task in which the perceptual color patch was replaced with a letter cue (‘R’ or ‘G’) that indicated the color participants had to imagine. The analyses revealed that imagined and perceptual colors both led to faster responses when the target color matched the cued color than when it mismatched the cued color. Interestingly, the magnitude of these congruency effects was significantly larger for the color imagery condition than for the perceptual color condition.

A second instance of color imagery resulting in stronger effects than color perception was observed in Chapter 4. Participants were required to provide a response that was presumed to produce a binding between that response and an imagined or perceptual color prior, and then to complete a perceptual color discrimination task that used the same key press responses. The analysis revealed that both color imagery and color perception groups produced event file binding effects – performance was efficient when the stimulus and response features completely matched or completely mismatched across the two displays on a trial, and inefficient when there was a partial match of these features across the two displays on a trial. However, there appeared to be an additional effect in the imagery condition – performance was especially efficient for the color imagery groups when both the color and response matched across the two displays on a trial. A similar pattern of results was observed in research exploring color and location bindings (Cochrane, Uy, Milliken, & Sun, in-prep). Here, a color cue was displayed in one of two locations, and participants performed a color discrimination task in which the color and location was systematically varied. The critical manipulation was whether participants had to imagine a color in response to a cue, or simply perceive the color of a cue. In the perceptual condition, responses were slower when the cue and target appeared at the same location than when the cue and target appeared in different locations. Also, there was no main effect of color congruency between the cue and target. In contrast, in the color imagery condition, performance was extremely efficient when both the color and location of the target match the cue relative to all other color/location binding conditions.

A possible reason that color imagery produces larger effects than color perception may be a difference in the attention afforded to the tasks. In the color perception conditions, participants are likely passively attending to the color, whereas in the imagery conditions participants are more likely to engage in active maintenance of color imagery across time. If these effects depend on the attention afforded to a particular color or the active maintenance of a color representation across time, then a sensible prediction is that color imagery should have a more profound effect on performance than color perception. Indeed, it has been demonstrated that the task requirement to maintain objects in working memory increases attentional capture effects relative to passively viewing objects (Awh & Jonides, 2001; van Mooreselaar, Theeuwes, & Olivers, 2014).

What processes are impacted by color imagery? Across the present thesis several processes affected by color imagery were discussed. The first of these is an attention process that leads to efficient allocation of spatial attention (Bergen & Julesz, 1983; Neisser, 1967; Treisman, 1988; Wolfe, 2001; 1994). This process is presumed to facilitate spatial orienting based on the match between a target template and an item in the search array. It is likely that this process was responsible for the effects in the singleton search experiments of Chapter 2 and 3, where it was demonstrated that color imagery can guide attention to congruent color targets. Further, this attentional process appears to be weakly influenced by target templates that are semantically based (see, Muller & Krummenacher, 2006; Theeuwes, Reimann, & Mortier, 2006; Wolfe, Horowitz, Kenner, Hyle, & Vasan, 2004). In summary, color imagery can form target templates that lead to efficient allocation of spatial attention to congruent targets. This attention process depends primarily on representations that are perceptually based and does not depend on repetition of associated responses.

A second set of processes affected by imagery are those associated with the formation of event files (Hommel, 1998; 2004; Hommel et al., 2001). These processes integrate virtually all object features, as well as associated responses and context. Further, event file formation does not depend on stimuli that are perceptually based, as binding effects were also produced with verbal responses to letter cues. In summary, event files can be formed with color imagery such that they influence the later processing of perceptual objects. Importantly, this event file binding process appears to be separate from the attention process that guides orienting (Hilchey, Rajsic, Huffman, Klein, & Pratt, 2018).

A third process affected by color imagery is that involved with the event-mediated inhibition effect. When an irrelevant task was performed in the temporal interval between color imagery and color discrimination tasks, performance was hindered when imagery and target colors were congruent. This effect appears to be produced by a habituation-like process that slows responding to repeated stimuli. This habituation process requires that stimuli are presented in the same location (Hilchey et al., 2017; Hu et al., 2010), and it does not appear to depend on associated responses (Francis & Milliken, 2003; Law, Pratt, & Abrams, 1995). Further, this habituation process appears to operate independent of the processes responsible for event file binding effects (Hilchey et al., 2017; Lorentz & Milliken, 2018). In summary, color imagery can produce a habituation-like effect for repeated perceptual stimuli. This effect is not related to event file binding, nor is it related to an attention process that facilitates orienting. It is unknown the degree to which this process is response-based and/or perceptually based.

The fourth process affected by color imagery reflects efficient processing of stimuli repeated in the same location. This process is separate from attention orienting processes as it depends on targets being presented at the same location (Hu et al., 2010; Pratt & Castel, 2001; Tanaka & Shimojo, 1996). It is an unresolved issue whether this process is related to response bias – this process could be related to the color imagery effects reported by Wantz et al. (2015) for which response biases cannot be ruled out (Chapter 3, Experiment 2; Wantz et al., 2015). In summary, color imagery facilitated performance for congruent color targets. This pattern of results appears not to be due to event file binding or attentional orienting processes. More research is required to determine whether such effects are due simply to the pre-activation of responses.

Conclusion

Over the course of this thesis, color imagery has been shown to have a profound influence on how we process objects in the visual world. When imagery effects occurred and did not occur has clarified the nature of several processes that are integral to perception. Specifically, color imagery can be used to establish a strong attentional template that overrides those guiding selection history effects. Color imagery can be used to form transient episodic representations that have a profound influence on the processing of perceptual stimuli. Color imagery can facilitate responding to congruent perceptual stimuli but also produce a habituation-like effect when a task intervenes between the imagery and perceptual events.

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