PREPARATORY EFFECTS IN POP-OUT SEARCH

PREPARATORY EFFECTS IN POP-OUT SEARCH: ARE TASK SETS BOUND TO STIMULUS LOCATION?

BY

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A Thesis Submitted to the School of Graduate Studies in Partial Fulfilment of the Requirements for the Degree Master of Science

McMaster University MASTER OF SCIENCE (2025) Hamilton, Ontario

(Psychology, Neuroscience & Behaviour)

TITLE: Preparatory Effects in Pop-Out Search: Are Task Sets Bound to Stimulus Location?

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PAGES: x, 60

Abstract

Preparing a selective response to a single item based on colour can influence subsequent search for a colour pop-out search target. One explanation of this preparatory effect is that the goal representation generated for the single item task is retrieved at the time of search via associative learning processes—akin to a task-switch cost. The current study tested this account by separating the single item and pop-out search tasks in space to reduce contextual overlap between them, which is known to reduce task switch costs, and encourage location-specific associative learning to occur. Surprisingly, this context manipulation had no impact on the magnitude of the preparatory effect. This result suggests that the preparatory effect may not reflect a carryover of higher order task set representations, but instead a carryover of lower order feature representations, in accordance with a dual-stage account of pop-out search.

Acknowledgements

McMaster feels like home, for more reasons than one. I am immensely grateful for having been able to attend this institution—a place both my parents graduated from and my Nonna worked for. I always knew I wanted to attend Mac one day, but I never could have dreamed of having an experience as enriching as this one.

First and foremost, thank you to Bruce Milliken for taking me on as a graduate student. It has been such a privilege to learn from you these past two years. I appreciate every meeting and discussion we have, from research to basketball. I'm grateful for all the time and effort you have put into guiding and teaching me and allowing me to explore a range of research topics. To my other committee members, Paul Andrews and Daniel Sanabria, thank you for supporting me on my research endeavors, no matter the change in direction. I greatly appreciate your time and our meetings, and the valuable insights you both bring.

David Shore, Joe Kim, Ellen MacLellan, and all other members, past and present, of the multi-lab community: thank you for creating such a supportive and collaborative environment. This community facilitates so much learning and growth and is one of the things I will miss most from our first-floor cognition wing. To have a group of intelligent, caring, and thoughtful academics show up to eagerly listen, engage in discussion, and provide insightful comments and feedback is invaluable. I have become a better researcher, writer, presenter, feedback-giver, and meme-translator because of it. I cherished every last meeting.

Ben Sclodnick, I would not be where I am today without your unwavering support, guidance, and willingness to always show up. From long days discussing data in the lab to planning and hosting Psychology LIVE, I wouldn't have wanted to do it with anyone else. I'll miss sharing an office with you (sad emoji face).

To the other members of the Milliken lab, Sevda Montakhaby Nodeh and Ver-Se Denga, thank you for being so welcoming and encouraging from the very beginning. I look up to and admire each of you as researchers, mentors, and women in academia (and in life, period). And Sevda, you are the reason I will always match my outfit to my posters (or as you have taught me, match my posters to my outfit).

To my incredibly intelligent, talented, funny, and caring friends and colleagues in the department—Fermin, Rachel, Marta, Jonathan, Aidan, Max, Rafa, Josh, Maya, and the rest of my cohort—I am so thankful to have shared this experience with you all. I have many faces to miss and memories to cherish.

My friends and family, how lucky I was to get to spend the last two years back home in Hamilton. Mom, Dad, and Mas, your endless support and encouragement gets me over every hurdle and through any bad day. NFBG. Camila, Lex, Lel, ShyShy, Maddie, Laynes, Bianca, Tiana—you were with me every step of the way, even when we were geographically apart. I am extremely lucky to have such a solid support system.

Thank you to the PNB faculty, administration, and front office staff (Taylor, for always finding what I lose before I realize I lost it), the PC custodial staff, the Psychology LIVE community, the McMaster Wrestling team, and MacOneAct. My McMaster graduate experience would not have been what it was without you. Thank you all so very much.

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Introduction

In any given moment, our visual systems process complex scenes with multiple people and objects. To what extent do we have control over what we attend to in these complex scenes? Do we consciously control our attention, or do properties of the stimulus determine what we attend to? These questions have been heavily debated in selective attention research and have given rise to much discussion of the distinction between bottom-up and top-down control of attention.

Bottom-Up Versus Top-Down Attentional Processes

The distinction between bottom-up and top-down attentional processes has played a formative role in selective attention research (Bravo & Nakayama, 1992). Bottom-up processes are thought to be automatic and require no intention or prior thought; they act to guide attention to areas of the visual scene that are distinct and that grab our attention—looking out at a field of green grass, your attention would be automatically drawn to a lone yellow dandelion. The automatic pull of attention to an object occurs because it is different from its uniform surroundings—it pops out because it is distinct from the background. As this form of bottom-up attention is driven automatically by signals from the environment, it is sometimes also referred to as stimulus-driven attention.

In contrast to bottom-up processes, top-down processes are thought to guide attention in a more controlled manner that relies on voluntary intention (Bravo & Nakayama, 1992). For example, top-down processes are critical to search a visual scene with a goal in mind—looking for a specific object in a messy room. In this manner, we use prior knowledge of the object's characteristics to guide our attention towards its current location. As this form of top-down attention depends on use of conscious goals and knowledge, it is sometimes also referred to as goal-driven attention.

Pop-Out Search

Visual search tasks are commonly used to explore attentional processes. These tasks involve displaying a target item that participants must detect in an array of distractor items. The speed and accuracy with which participants detect the target item can depend on how similar it is to the distractors, and how similar the distractors are to each other (Duncan & Humphreys, 1989). For example, if the colour of the distractor items is the same and contrasts significantly with the colour of the target item, the target item becomes more salient. This salient target item "pops-out" among the homogenous distractors, resulting in rapid attention capture and fast response times. Due to this seemingly automatic target detection and response process, pop-out search effects have historically been thought to be driven by bottom-up attentional processes.

Seminal evidence was provided for the contribution of bottom-up attention to pop-out search by Treisman and Gelade (1980). They found that under certain conditions search response time means remained the same as the number of distractor items increased. Treisman and Gelade manipulated display size in search trials in which the target differed from all distractors on the basis of a single feature, such as colour or shape. Search performance for these single feature targets did not depend on the number of distractors; mean reaction times remained the same as display size increased (Experiment 1). These flat search slopes suggested that participants did not search through the items serially, checking each distractor to rule it out before shifting attention to the next item, and ultimately detecting the target. Such an item-by-item search can be thought of as involving top-down processes, as it requires voluntary intention and a conscious goal. Therefore, bottom-up attention was deemed to be involved in pop-out search effects. However, the clear presence of bottom-up attention does not preclude the possibility that top-down attention may also be playing a role.

Bravo and Nakayama (1992) explored whether top-down knowledge of a pop-out feature could facilitate search. They conducted an experiment that manipulated the predictability of the target and distractor colours. In their blocked condition, participants responded consistently across all trials to search displays with red targets in an array of green distractors. In their mixed condition, participants responded to trials that changed target and distractor colour unpredictably (i.e., red targets amongst green distractors or green targets amongst red distractors). Therefore, participants in the blocked condition could use knowledge of the target colour—top-down attentional processes—to guide search, while participants in the mixed condition could only rely on the target popping out against distractors—bottom-up attentional processes—to guide search. If bottom-up attention is solely involved in pop-out search effects, then search performance in the blocked condition should show no advantage relative to the mixed condition. Yet, Bravo and Nakayama found that the participants in the blocked condition produced faster search performance than participants in the mixed condition. They attributed this difference to the use of top-down knowledge by participants in the blocked condition. This finding therefore suggests that top-down mechanisms can guide attention in pop-out search tasks.

Priming of Pop-Out and Selection History

Bravo and Nakayama (1992) suggested top-down knowledge of a stimulus can help guide attention because they found participants were faster at responding to pop-out targets when target colour was identical across trials than when it was mixed. However, Maljkovic and Nakayama (1994) challenged this interpretation. They pointed out that participants in the blocked condition were repeatedly presented with the same physical target representations and suggested that there is opportunity for priming to occur. Perhaps faster search performance in the blocked condition compared to the mixed condition was due to priming by the target colour on preceding trials, not prior knowledge of the target colour. To investigate this inter-trial priming hypothesis, they altered Bravo and Nakayama's method to make search target colour alternation vary in predictability across several mixed contexts. This method allowed them to compare performance in contexts in which the probability of target colour alternation was at the level of chance (i.e., $p = .50$) and the probability of target colour alternation was greater than chance (e.g., $p = .90$; Experiment 2). If top-down knowledge of the target colour drives efficient search, then participants should be particularly fast on search trials with alternating targets that are highly predictable. Yet, Maljkovic and Nakayama found that search performance was slow rather than fast in a context with highly predictable alternating targets. This result implied that faster search performance for blocked conditions with perfectly predictable repeating targets reflects trial by trial priming rather than target predictability. By this view, responding to the same target colour repeatedly creates a short-term memory of that target colour that primes search for the same target on the following trials and results in faster search times. Maljkovic and Nakayama deemed the consequence of this short-term memory the *priming of pop-out* effect.

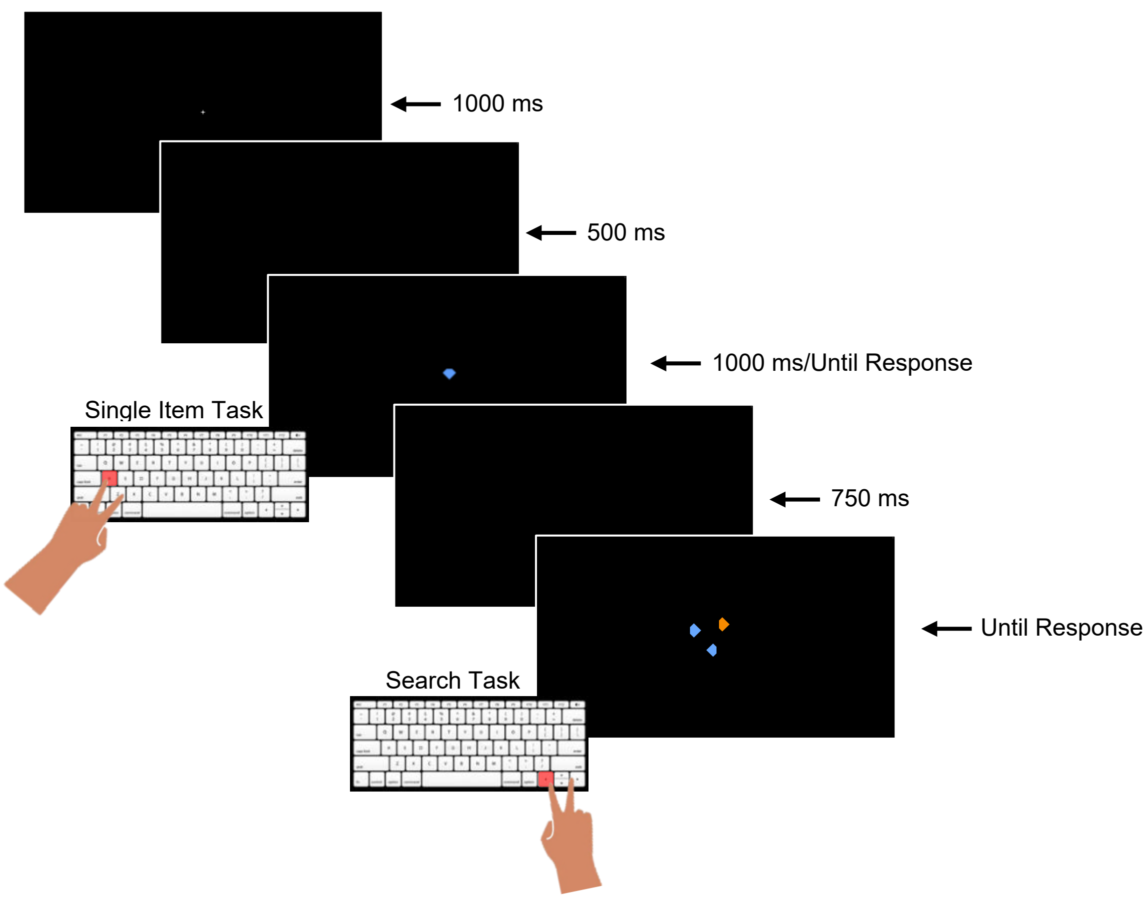
Other studies have since provided further evidence for the involvement of memory in attentional control. Awh et al. (2012) argued against the dichotic view of top-down versus bottom-up attentional control processes and proposed an alternate framework that includes a third attention control process. This third process centers on lingering effects of prior experience on attentional control, for which Awh et al. introduced the term *selection history*. Neither specifically top-down nor bottom-up, selection history is thought to bias selection implicitly due to carryover of prior visual representations to current attentional selection. The new framework of Awh et al. therefore proposes three distinct sources of selection bias: our current goals (top-down), physical saliency (bottom-up), and selection history. By this view, pop-out search might be accommodated without reference to top-down processes, and instead could involve only bottom-up salience and selection history (Theeuwes, 2018).

Preparation–Search Match Effect

Sclodnick et al. (2024) set out to address specifically whether top-down acts of preparation on their own can produce preparation history effects in pop-out search. To do this, they aimed to create a method that would allow investigation into the contribution of high-level task goals to preparation history effects without target feature repetition as a confound. Therefore, they introduced a search method that allowed preparation of task goals to be manipulated separately from the repetition of target features. Their new method involved the addition of a single item directly before each search display (see Figure 1). The single item was a blue or orange diamond presented centrally, and it was missing either the top or bottom corner. The search display consisted of a blue target diamond and orange distractor diamonds (or vice versa) missing either the left or right corners. The single item task involved inducing top-down preparation for a particular colour; participants were instructed to respond only to single items of a certain colour (i.e., blue) and to ignore them otherwise. The response to the single item involved indicating the missing corner of the diamond with a key press (‘A’ key for top corner missing and ‘Z’ key for bottom corner missing). Participants were to respond always in the search task to the missing corner of the odd-coloured target (left or right arrow key). In all, the single item task was thought to prepare participants for a certain colour at the beginning of each trial, whereas that preparation was nominally irrelevant to the following search task (see Figure 2 for examples of trial types).

Figure 1

Sclodnick et al. (2024) Single Item and Search Display Method



Note. Participants selectively responded to the missing corner of the single item only if that single item was a particular colour. Participants always responded to the missing corner of the odd-coloured target in the search display regardless of its colour.

Figure 2

Sclodnick et al. (2024) Trial Types

Single Item Response	"top"	no response	no response	"bottom"
Feature Repetition	switch	repeat	switch	repeat
Preparation–Search	mismatch	mismatch	match	match

Sclodnick et al. (2024) hypothesized that if induced preparation for the single item task can carry over to influence performance in the following search task, then search performance should depend on whether the prepared single item task colour matches or mismatches the search target colour (see Figure 2). The results of their study aligned with their hypothesis; they found that responses were faster for search targets that matched the colour of the prepared-for single item than for search targets that mismatched the colour of the prepared-for single item. For example, when participants prepared to respond to a blue single item, they were faster to respond to a blue than orange search target—no matter the colour of the single item on that trial. This result suggests that preparation to respond to a particular feature on the single item task carried over to the search task and impacted participants' performance—deemed the *preparation–search match effect.* Sclodnick et al.'s result suggested that top-down preparation can affect goal-related representations, which can carry over to produce a preparation history effect—a form of selection history effect (Awh et al., 2012).

Task Sets, Task-Switching Costs, and Associative Learning

Task-switching is the process by which individuals transition between different task sets, which are mental representations that specify how to interpret stimuli and respond accordingly (Monsell, 2003). Task sets guide behaviour by determining what information to attend to, how to interpret stimuli, and what responses to make; each involving distinct goals, rules, and attentional priorities (Rogers & Monsell, 1995). We have many task sets stored in our memories, which we've acquired through practice—and the more we practice a task, the easier it is to re-enable the task set (Monsell, 2003). Task sets can be manufactured in lab settings when participants are taught how to execute experiment tasks.

Standard task switching experiments involve two or more simple tasks, each requiring a different level or kind of interaction with the presented stimuli. On some trials the task changes (switch trials) and on some trials the task stays the same (repeat trials); performance in switch trials is compared with performance in repeat trials. A robust finding is that there is a cost when switching between tasks that results in slower reaction times and increased error rates on the consequent task (Jersild, 1927; Spector and Biederman, 1976; Allport et al., 1994; Rogers & Monsell, 1995; Monsell, 2003; Kiesel et al., 2014). These switch costs occur due to the time needed to reconfigure task set in order to prepare to respond with the correct stimulus-response mapping (Monsell, 2003; Rogers & Monsell, 1995). Switch costs can also occur when tasks are similar in nature and the presentation of the task display causes retrieval of processes associated with it from the other task—called *task set inertia* (Allport et al., 1994). In this case, time is needed for a participant to overcome task-set inertia and resolve interference from the memory of the last task.

Contextual overlap across tasks heavily affects switch costs (Mayr and Bryck, 2007). Mayr and Bryck conducted an experiment where participants were cued to evaluate either the colour (red or green) or orientation (horizontal or vertical) of a large square stimulus, that could appear on the left or right side of a screen. The overlap condition showed participants the square in the same location, no matter the task. The no-overlap condition showed participants the square on the left side of the screen for the colour task and on the right side of the screen for the orientation task. If contextual overlap indeed affects switch costs, performance in the overlap condition should be slower and show a larger switch cost than performance in the no-overlap condition. Mayr and Bryck found that participants made more errors and were slower overall in the overlap condition than participants in the no-overlap condition. They proposed that switch costs were reduced in the no-overlap condition because distinct location cues for the two tasks allowed location to serve as a cue to reinstate the task set that was uniquely associated with that location. This proposed associative learning process would therefore result in an automatic cueing and reinstatement of the appropriate task set. In short, this proposal suggests that assigning two different tasks to two separate locations may permit distinct task representations to become associated to those locations, which in turn helps participants switch effectively between the two tasks.

Other experiments have provided further evidence for spatial location associative learning facilitating effective task switching performance. Leboe et al. (2008) demonstrated this switch cost reduction by having participants perform two different response judgement tasks on either the top or bottom of the screen (Experiment 2). Participants were presented with animal names, and the task was to discriminate the animal’s size (big vs. small) or habitat (land vs. sea). The discrimination task required was cued with a row of symbols above and below the animal name (i.e., pound signs for animal size and asterisks for habitat). One of the name locations (top or bottom) was more likely to require participants to task switch from the previous trial and the other was more likely to require participants to repeat the task from the previous trial. The results showed that task switching costs were higher when the animal name appeared at a location that was mostly associated with task repetitions, than when the name appeared at a location that was mostly associated with task switches. This finding suggests that participants associatively learned the mapping between specific screen location and likelihood of a task switch or task repetition. Onset of an animal name at a particular location would then cue the retrieval of these associatively learned processes, facilitating task switching for animal names that appeared at a location that was most often associated with task switching.

Though not a task switching study, the results of Crump et al. (2006) also demonstrate that spatial context can serve as a basis for associative learning that ultimately influences what are often thought to be higher order cognitive control processes. In this study, participants performed a Stroop-like task (Experiment 2A). In a typical Stroop task, participants name aloud the ink-colour of a colour word (e.g., saying “red” when presented with the word “blue” in red ink), and the Stroop effect refers to faster colour naming on congruent trials (e.g., “red” in red) than on incongruent trials (e.g., “red” in blue) (Stroop, 1935). In Crump et al.’s adaptation of the Stroop method, participants were presented with a colour word prime (in white) followed by a coloured rectangle that appeared above or below fixation. The task was to name aloud the colour of the rectangle quickly and accurately. One of the rectangle locations (above or below fixation) was associated with a high proportion of congruent trials (where the prime word matched the rectangle colour), while the other location was associated with a high proportion of incongruent trials. The results showed a larger Stroop effect (faster reaction times for congruent than incongruent trials) at the high proportion congruent location compared to the low proportion congruent location. These findings provide additional evidence that spatial location can play an important role in an associative learning process that facilitates rapid and flexible selection of higher order task-relevant processes.

Present Study

As described above, there is strong evidence in the literature to support the idea that spatial context can play an important role in associative learning involving higher order representation such as task sets. Moreover, this associative learning appears to serve as a basis for facilitated task-switching (Mayr & Bryck, 2007; Leboe et al., 2008). In the present study, we extended this logic to the study of processes presumed to contribute to preparation effects in pop-out search, and in particular the preparation–search match effect reported by Sclodnick et al. (2024).

The preparation–search match effect could be thought of as an effect that captures a difficulty in switching from a task set involving discrimination of the colour of a single item to a task set involving search for an odd colour (see Figure 1). If indeed this effect reflects a form of task switch cost, then we might expect that it occurs, at least in part, because both tasks (discriminate single item colour, search for odd colour) are applied to stimuli that occur at the same spatial location. Consequently, the task switch cost associated with doing two different tasks in sequence may be exacerbated by the contextual overlap associated with the target stimuli for those two tasks. In all prior studies of the preparation–search match effect, the single item and search display have both been presented in the center of the screen, one after the other—that is, with substantial overlap in spatial context. Moreover, participants are presented with similar stimuli across the two tasks (blue and orange diamonds) yet must adhere to a different set of rules (i.e., respond only to blue single items, respond to all odd-coloured search targets). Thus, Sclodnick et al.'s method may be sensitive to the same associative learning processes that mediate task-switching costs. If so, then separating the single item and search display so that they belong to two clearly different spatial contexts may help participants differentiate between the two tasks and task-switch more effectively.

The goal of the present research program was to examine if location-specific associative learning might influence the preparation–search match effect. By manipulating whether or not the single item and search tasks are consistently associated with distinct spatial contexts, we test whether the carryover of preparation can be reduced through associative learning. This aim is an important one as it also would begin to address whether the preparation–search match effect should be thought of as driven by lower-level attentional guidance mechanisms, or higher order processes such as task set retrieval.

Experiment 1

Experiment 1 was a first attempt to examine whether associative learning involving task sets contributes to the preparation–search match effect. This issue was addressed by introducing two different task locations in a method that tests whether location-specific associative learning involving task sets can impact the preparation–search match effect. In the consistent condition, the single item always appeared on the left side of the screen and the search display always appeared on the right side of the screen, or vice-versa. In the random condition, the single item appeared on a random side of the screen and the search display always appeared on the opposite side of the screen. If participants can associatively learn the relation between a task and the side of the computer screen on which it appears, then they may also more easily differentiate between tasks and switch between them more efficiently. This increased efficiency in task switching could reduce the carryover of the single item task set representation (i.e., respond only to blue single items) to the search task, and thereby reduce the preparation–search match effect.

Methods

Participants

The data collection process was approved by the McMaster Research Ethics Board. Seventy-three McMaster University undergraduates (M_{age} = 19.6, SD_{age} = 1.99; 77% identified as women) participated in-person for course credit. All participants reported normal or corrected-to-normal vision and met a priori inclusion criteria of 90% discrimination response accuracy (i.e., which corner of the diamond is missing) to the single items and over 80% discrimination response accuracy in all conditions of the search target task. We excluded one participant whose hit-minus-false-alarm rate for the single items was below an a priori inclusion criterion of .80. Our final sample size was therefore 72 participants randomly assigned to the consistent (n = 36) or random (n = 36) conditions.

Sample size was supported by a power analysis using the SuperPower Shiny app (Lakens & Caldwell, 2021). This simulation power analysis assumed an alpha level of .05 and was based on data from a pilot study (n = 48) that also examined whether the preparation–search match effect varied as a function of consistent versus random mapping of tasks (single item vs search) to two spatial contexts. This power analysis determined that a sample size of 36 participants per group would be sufficient to detect an effect of the same size observed in that pilot study, using an analysis strategy that treats the first block of trials as practice and the following two blocks as the focal trials in which the targeted learning effect would be expressed.

Apparatus and Stimuli

The experiment was programmed using PsychoPy and run online via Pavlovia. All diamond stimuli had a side length of 1.5 cm and a missing corner that measured 0.5 cm in length from the tip of the removed corner towards the center of the diamond. Single items were missing either the top or bottom corner, whereas search targets and distractors were missing either the left or right corner. Diamond stimuli were displayed on a black background and were blue (hex: #68A7FC) or orange (hex: #F48B00). To generate each search display, target locations were randomly generated based on an imaginary coordinate circle (r = 3.6 cm). Five distractors (of a different colour than the single item) with one corner missing were spaced equally around the coordinate circle. Single item and search displays on each trial were presented one after the other on opposite sides of the screen (15 cm from the center to the left or right). A thin vertical white line was added in the center of all trial screens with a small break in the middle for the fixation cross to appear.

Procedure

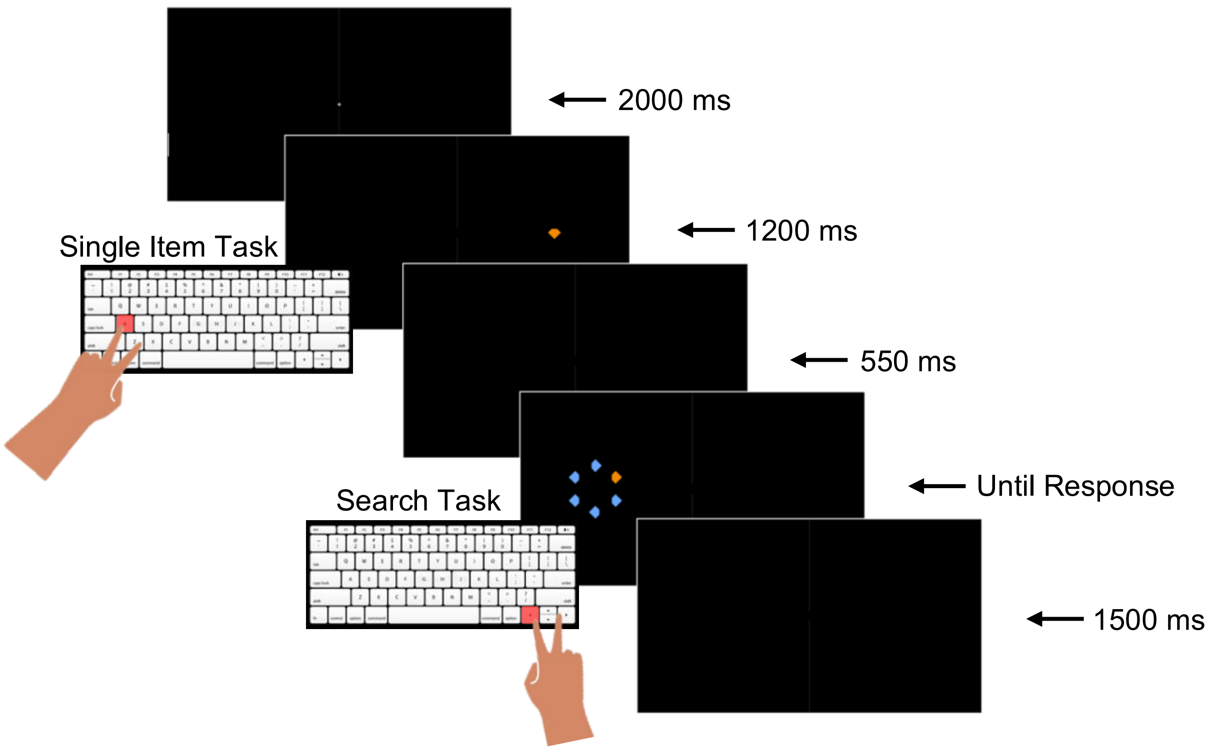
The experiment took participants approximately 50 minutes to complete. Participants were brought into the lab where they read and signed a consent form and sat at a desk facing a computer. They were asked to read through a set of instructions on the computer that included illustrations of the procedure with accompanying text. Once participants finished reading, they were asked to explain the instructions back to the researcher to ensure they understood correctly. The researcher then measured the distance between the participants and the computer to ensure they were all approximately 57 cm from the screen.

Participants first completed 24 practice trials which provided on-screen feedback when an error was made. The practice trials were followed by three blocks of 120 experimental trials (360 total; see Figure 3 for an example of a single trial). After each block of 120 trials, the experiment paused, and participants were given the option to take a break for up to three minutes. Trials resumed when the participants chose to continue or once three minutes had passed. Each trial began with a central white fixation cross that lasted for 2000 ms. Participants were instructed to keep their gaze fixated on the fixation cross for as long as it was on the screen. The single item appeared next and remained on the screen for 1200 ms. Participants were to respond to the missing corner (top/bottom) of the single item only if it was a particular colour (blue for one group, orange for the other group, counter-balanced across participants). They used their left hand to respond, hitting the “A” key for top and “Z” key for bottom. The single item was followed by a blank screen that lasted for 550 ms. The search display appeared next and remained on the screen until a response was made.

Participants were to respond on all trials to the odd-coloured target in the search display by reporting the missing corner (left/right) using their right hand ("left" arrow key for left and "right" arrow key for right). A blank screen followed for 1500 ms before the next trial began.

Figure 3

Example Trial in Experiment 1



Note. Participants responded selectively to the missing corner of the single item only if it was a particular colour (i.e., only if was blue/orange). Participants always responded to the missing corner of the odd-coloured target in the search display.

Design

Participants were randomly assigned to the consistent or random condition. In the consistent condition, the single item always appeared on the same side of the screen (15 cm from the center to the left or right). The search display always appeared on the opposite side of the screen to the single item. In the random condition, single items randomly appeared on either the right or left side of the screen (50% on the left and 50% on the right). Participants in the random condition had no way of knowing on which side the single item would appear. Search displays in the random condition always appeared on the opposite side to the single item. Half of the participants (n = 36) prepared to respond only to blue single items and the other half prepared to respond only to orange single items in the single item task. Half of the participants in the consistent condition (n = 18) had the single item always appear on the left side of the screen and the other half had the single item always appear on the right side of the screen.

There were three primary independent variables in the design. The first variable was manipulated between-subjects and was labeled *condition*; it captured whether the stimuli for the single item and search tasks appeared on consistent or random sides of the screen. The second variable was manipulated within-subjects and was labeled *preparation–search*; it captured whether the colour prepared for in the single item task matched or mismatched the search display target colour. The final independent variable was also manipulated within-subjects and was *feature repetition*; it captured whether the colour of the single item in the single item task was the same as (repeat) or different than (switch) the colour of the search task target. All possible trial conditions generated by combining these independent variables are illustrated in Figure 4.

Figure 4

Trial Types When Participants Are Prepared to Respond to Blue Single Items

Single Item Response	"top"	no response	no response	"top"
Feature Repetition	repeat	switch	repeat	switch
Preparation–Search	match	match	mismatch	mismatch

Note. The trials depicted here assumed that participants responded only to blue single items. For participants who responded only to orange single items, the levels of "Single Item Response" and "Preparation–Search" were reversed. The size of the diamond stimuli is enlarged relative to the screen size (i.e., they are not presented to scale) to ease visualization of the conditions for the reader; refer to Figure 3 for an accurate depiction of the size of stimuli in proportion to screen size.

Results

Only correct responses to the single item task were included in single item response time (RT) analyses, and only correct responses to the search task after a correct response to the single item were included in search RT analyses. We then excluded from analyses all trials with RTs below 200 ms or above 3000 ms ($<$ 0.1% of data), as they were unlikely to reflect task-relevant processes (Miller, 2023). The first block of 120 trials was treated as practice and excluded from analyses as per our power analysis on the pilot study, however the interested reader can refer to the appendix for analyses that include all three blocks. Mean RTs were then computed based on the remaining observations.

Single Item Task Performance

Participants demonstrated high overall accuracy in responding selectively based on colour to the single item ($M_{\text{hit minus false alarm}}$ = 95.7%). Mean discrimination accuracy on trials that required a response was 98.5%. An independent samples t-test was conducted to compare mean single item RTs between the consistent (M = 668 ms, SD = 104 ms) and random (M = 696 ms, SD = 105 ms) conditions. There was no significant difference in mean RTs between the conditions, $t(67.19) = -1.57$, $p = .122$.

Search Task Performance

Search mean RTs and corresponding error rates were submitted to mixed factor analyses of variance (ANOVA) that treated preparation–search (match/mismatch) and feature repetition (repeat/switch) as within-subjects variables and condition (consistent/random) as a between-subjects variable. An alpha level of .05 was used to determine statistical significance.

Mean search RTs and corresponding error rates for all conditions are shown in Table 1. Mean search RTs collapsed across feature repetition are displayed in Figure 5. The pattern of data in Figure 5 suggests that there was a strong preparation–search match effect, but that this effect does not appear to differ across consistent and random conditions. These observations are supported by the analyses described below.

Table 1

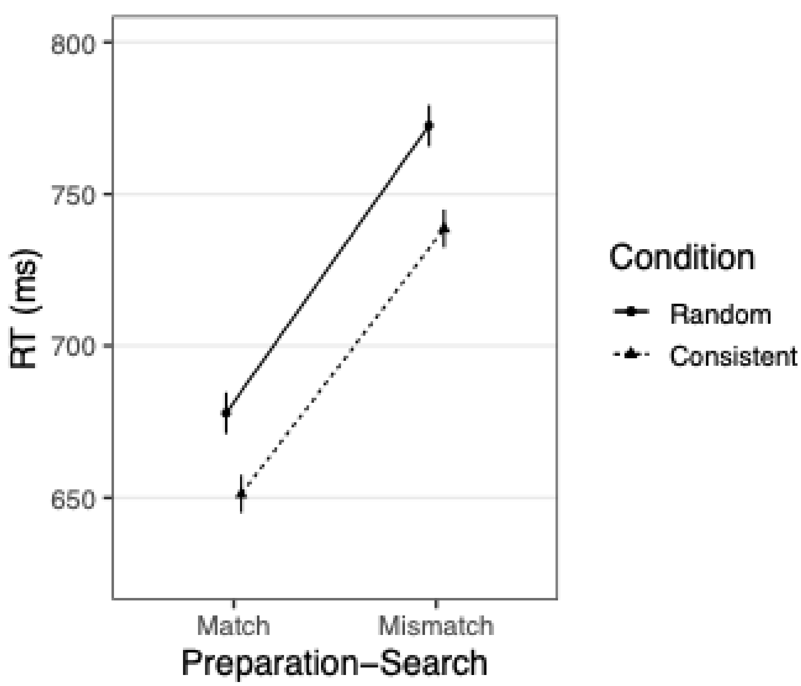
Mean Response Times (RT) and Error Rates in Experiment 1.

	Feature Switch				Feature Repetition			
	Match		Mismatch		Match		Mismatch	
	RT	Err Rate	RT	Err Rate	RT	Err Rate	RT	Err Rate
Consistent	651 (77.7)	1.49 (2.02)	740 (114)	3.01 (3.84)	651 (78.2)	1.49 (2.23)	737 (114)	2.19 (3.06)
Random	672 (77.6)	1.56 (3.02)	780 (113)	2.70 (3.14)	683 (80.9)	1.81 (2.97)	765 (95.9)	2.72 (3.72)

Note. Standard deviations are presented in parentheses. The mean response times and error rates by condition from blocks two and three (see appendix for all three blocks).

Figure 5

Mean Response Times (RT) to Search Targets in Experiment 1



Note. Mean RTs in the search task here are collapsed across the feature repetition variable. Error bars depict the standard error of the mean adjusted to eliminate between-subjects variability (Cousineau, 2005; Morey, 2008).

The analysis revealed a significant main effect of preparation–search, $F(1,70) = 191.88$, $p < .001$, $\eta_p^2 = .733$. Search responses were 92 ms faster when the colour of the search target matched the colour prepared for in the single item task (M = 664 ms, SD = 74.1 ms) than when the colour of the search target mismatched the colour prepared for in the single item task (M = 756 ms, SD = 105 ms). Most important, the interaction between condition and preparation–search was clearly not significant, $F(1,70) = 0.31$, $p = .582$, $\eta_p^2 = .004$; the preparation–search match effect did not differ across the consistent and random conditions.

The analysis of search task error rates also revealed a significant main effect of preparation–search, $F(1, 70) = 14.31$, $p < .001$, $\eta_p^2 = .170$. This effect was similar to the corresponding effect in the search RT analysis, with lower error rates for the match condition than for the mismatch condition (see Table 1). The interaction between condition and preparation–search was not significant, $F(1, 70) = 0.02$, $p = .877$, $\eta_p^2 = < .001$.

Discussion

There were two key findings in this experiment. First, the results reflected a successful replication of the preparation–search match effect reported by Sclodnick et al. (2024). Specifically, participants responded faster when the search target colour matched the colour prepared for in the single item task than when the search target colour mismatched the colour prepared for in the single item task. Second, consistency of mapping of single item and search tasks to locations did not influence the preparation–search match effect. This result suggests that location-specific associative learning involving task sets did not contribute to more efficient task set switching between the single item and search tasks.

Experiment 2A and 2B

Experiment 2A was a second attempt to examine whether associative learning involving task sets contributes to the preparation–search match effect. This issue was addressed again by introducing two different task locations in a method that tests whether location-specific associative learning involving task sets can impact the preparation–search match effect. However, there were several minor changes to the method relative to Experiment 1.

The primary change in method in Experiment 2A was to relax control over participants' gaze prior to single item onset. Whereas in Experiment 1 participants were required to maintain focus on fixation prior to single item onset, in Experiment 2A there was no such requirement. However, this change in method for Experiment 2A introduced a potential challenge to interpreting results. If an effect were found in Experiment 2A, it would be unclear whether that effect was due to associative learning that binds task sets to consistent spatial contexts for the following reasons. If participants in the consistent condition could shift their gaze to where they knew the single item would appear prior to its onset, it seems possible that they might then respond to the single item and switch their attention to the search task efficiently simply by virtue of the single item appearing where it was expected—resulting in fast search responses due to having pre-oriented to the single item location, rather than to associative learning. Therefore, Experiment 2B was run as a control experiment that examined the influence of pre-orienting to the single item location alone on subsequent search performance.

To address this issue, Experiment 2B presented a fixation cross on either the left or right side of the screen and asked participants to shift their attention to this location prior in anticipation of single item onset. On valid trials the single item appeared at this cued location, whereas on invalid trials the single item appeared at the location opposite the cued location. Importantly, the cue appeared on the left side of the screen as often as on the right side of the screen. This aspect of the method eliminated the opportunity for participants to use location-specific associative learning to switch between tasks. Therefore, if an effect of single item *validity* on search performance were to be found in Experiment 2B, any effect observed in Experiment 2A might then be attributed to spatial orienting rather than to associative learning.

One additional change to the method of Experiment 1 is also relevant. The preparation–search match effect reported originally by Sclodnick et al. (2024) has subsequently been found to have two components: one related to attending and responding to a relevant single item and another related to ignoring and not responding to an irrelevant single item. The method used in Experiment 1 measured both of these components. In Experiments 2A and 2B we chose to measure just the attending component of the effect. To do so, we presented half of the participants with blue or green single items and the other half of the participants with orange or green single items. Participants responded selectively to blue single items in the first group, and to orange single items in the second group. Green single items were always irrelevant, and search displays always included only blue and orange items, as in Experiment 1.

Methods

Participants

The data collection process was approved by the McMaster Research Ethics Board. All participants reported normal or corrected-to-normal vision and met our a priori inclusion criteria of 90% discrimination response accuracy (i.e., which corner of the diamond is missing) to the single items and over 80% discrimination response accuracy to the search targets in our critical conditions.

Experiment 2A. Seventy-two McMaster University undergraduates (M_{age} = 18.6, SD_{age} = 1.51; 73% identified as women) participated in-person for course credit. We had one participant whose hit-minus-false-alarm-rate was .70, which was below an a prior inclusion criterion of .80, however we chose to include this participant's data to maintain equal sample sizes. Our final sample size was therefore 72 participants randomly assigned to the consistent (n = 36) or random (n = 36) conditions.

Sample size was supported by the power analysis used for Experiment 1. This simulation determined a sample size of 36 participants per group would be sufficient to detect the effect observed in our pilot study with power of .80 using the second and third block of trials in the analyses.

Experiment 2B. Thirty-two McMaster University undergraduates (M_{age} = 18.0, SD_{age} = .47; 75% identified as women, 1 gender non-conforming) participated in-person for course credit. All participants met an a priori inclusion criterion of .80 for hit-minus-false-alarm rates to the single items. Our final sample size was therefore 32 participants.

Sample size was supported by a power analysis using the SuperPower Shiny app (Lakens & Caldwell, 2021). This simulation power analysis assumed an alpha level of .05 and was based on data from the same pilot study as described earlier. In this case, the simulation treated the consistent versus random mapping condition in that pilot study as a within-subjects variable, as the key interaction here involved a within-subject manipulation of spatial validity. This power analysis determined that a sample size of 32 participants would be sufficient to detect this interaction with power of .80 using the second and third blocks of trials in the analyses.

Apparatus and Stimuli

The apparatus and stimuli in both Experiments 2A and 2B were identical to Experiment 1, apart from the following changes. The single-item colour was blue or green (hex: #00A700) for one group, and orange or green for the other group. The white vertical line presented in the center of the display at the outset of trials in Experiment 1 was not displayed in Experiments 2A and 2B. Finally, the single item and search task stimuli were centered 8 cm to the left/right of the screen center in Experiments 2A and 2B, as opposed to 15 cm to the left/right of screen center in Experiment 1.

Procedure

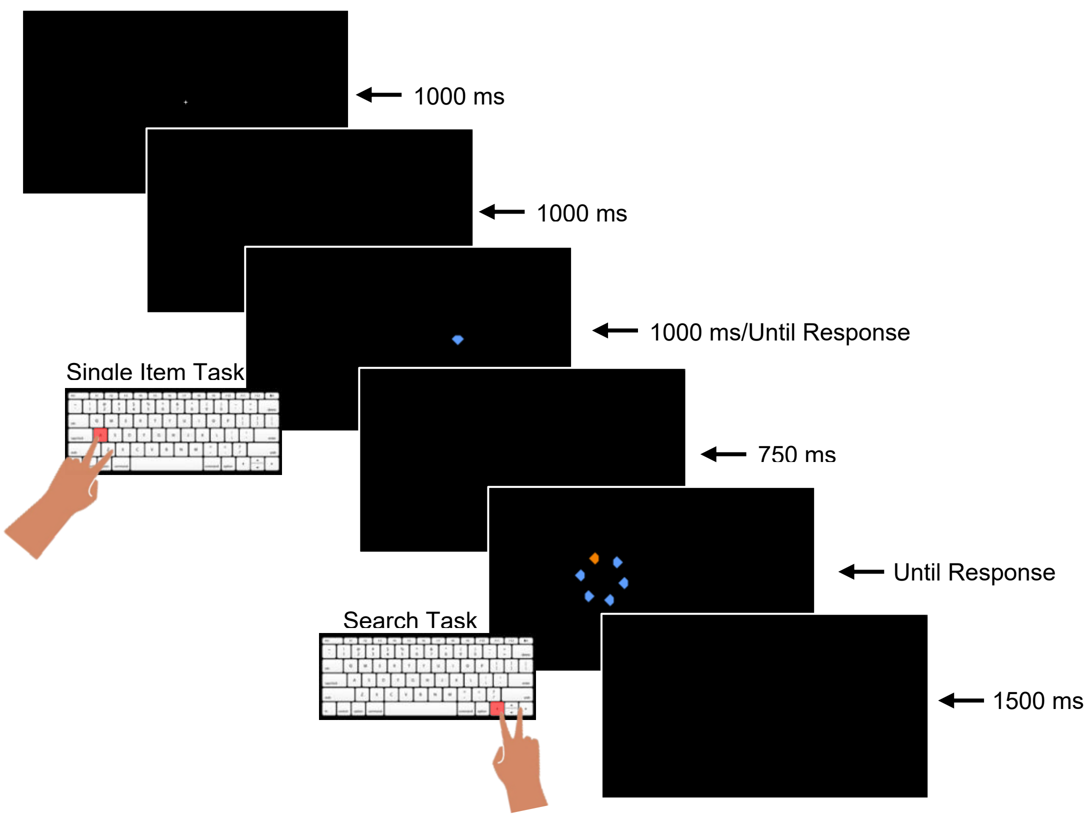
The experiment took participants approximately 50 minutes to complete. Participants were brought into the lab where they read and signed a consent form and sat at a desk facing a computer. They were asked to read through a set of instructions on the computer that included illustrations of the procedure with accompanying text. Once participants finished reading, they were asked to explain the instructions back to the researcher to ensure they understood correctly.

Participants first completed practice trials which provided on-screen feedback when an error was made. The practice trials were followed by three blocks of 120 experimental trials. After each block of 120 trials, the experiment paused, and participants were given the option to take a break for up to three minutes. Trials resumed when the participants chose to continue or once the three minutes were up. Each trial began with a central white fixation cross that lasted for 1000 ms. Then a blank screen appeared for 1000 ms. The single item appeared next and remained on the screen until a response was made or 1000 ms had elapsed. This change in timing for the single item ensured that there was a fixed amount of time between the single item response and the search display onset, rather than a fixed amount of time between the single item onset and the search display onset as in Experiment 1. With this change in method, if a participant responded particularly fast to the single item, they would have the same amount of time until the search display appeared as a participant who responded slower to the single item. In other words, this change in method eliminated any extra time to get ready for the search task associated with participants responding quickly to single items. As in Experiment 1, participants were to respond to the missing corner (top/bottom) of the single item only if it was a particular colour (blue for one group, orange for the other group, counter-balanced across participants). They used their left hand to respond, hitting the “A” key for top and “Z” key for bottom. Participants were presented with either a single item that was the colour they were prepared to respond to (blue or orange) or a single item that was green, and therefore not responded to. The single item was followed by a blank screen for 750 ms. The search display appeared next and remained on the screen until a response was made. Participants were to respond always to the odd-coloured target in a search display by reporting the missing corner (left/right) using their right hand ("left" arrow key for left and "right" arrow key for right). A blank screen followed for 1500 ms before the next trial began.

Experiment 2A. Participants completed 24 practice trials. See Figure 6 for an example of a single trial.

Figure 6

Display Sequence for a Trial in Experiment 2A

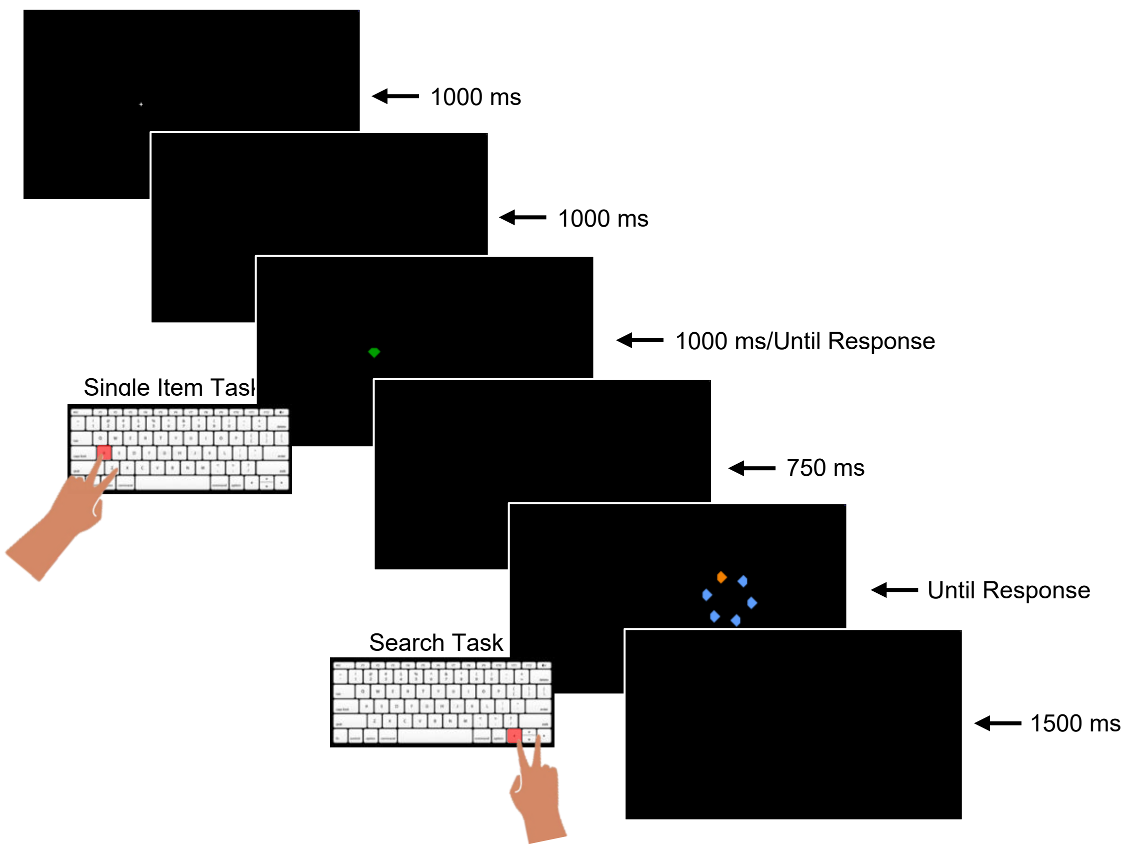


Note. Participants selectively responded to the missing corner of the single item only when that single item was a particular colour. Participants always responded to the missing corner of the odd-coloured target in the search display.

Experiment 2B. All aspects of the procedure were the same as Experiment 2A with the following exceptions. Participants completed 32 practice trials. The single item appeared on the same side of the screen as the fixation cross cue on 80% of trials and appeared on the opposite side of the screen to the fixation cross cue on 20% of trials. See Figure 7 for an example of a single trial.

Figure 7

Display Sequence for a Trial in Experiment 2B



Note. Participants selectively responded to the missing corner of the single item only when that single item was a particular colour. The single item appeared on the same side as the fixation cross 80% of the time and appeared on the opposite side to the fixation cross 20% of the time. Participants always responded to the missing corner of the odd-coloured target in the search display.

Design

Experiment 2A. Participants were randomly assigned to the consistent or random condition. In the consistent condition, the single item always appeared on the same side of the screen (left or right). The search display always appeared on the opposite side of the screen to the single item. In the random condition, single items randomly appeared on either the right or left side of the screen (50% on the left and 50% on the right). Search displays in the random condition always appeared on the opposite side to the single item. Half of the participants in each of these two conditions prepared to respond only to blue single items in the single item task and the other half prepared to respond only to orange single items in the single item task. Participants always ignored green single items. For the consistent condition, the side of the screen (left/right) on which the single item appeared consistently was also counterbalanced across participants.

There were three primary independent variables in the design. The first variable was manipulated between-subjects and was labeled *condition*; it captured whether the stimuli for the single item and search tasks appeared on consistent or random sides of the screen. The second variable was manipulated within-subjects and was labeled *preparation–search*; it captured whether the colour prepared for in the single item task matched or mismatched the search display target colour. The final independent variable was also manipulated within-subjects and was labeled *search relevance*; it captured whether the colour of the single item in the single item task was orange or blue (*search relevant*) or green (*search irrelevant*). All possible trial conditions generated by combining these independent variables are illustrated in Figure 8.

Figure 8

Trial Types in Experiment 2A

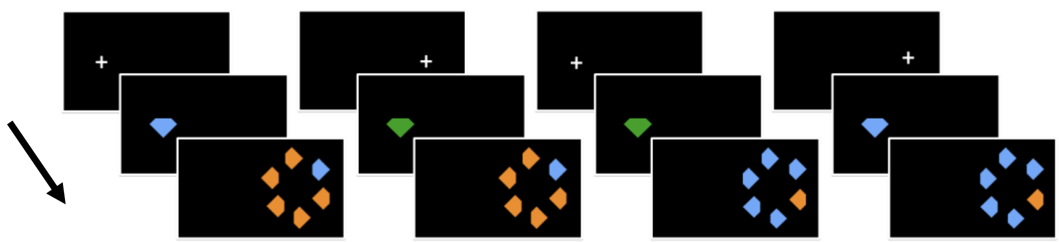
Single Item Response	"top"	no response	no response	"top"
Search Relevance	relevant	irrelevant	irrelevant	relevant
Preparation–Search	match	match	mismatch	mismatch

Note. The trials depicted here assumed that participants responded only to blue single items. For participants who responded only to orange single items, blue single items would be replaced by orange single items in the figure above (only orange and green). The size of the diamond stimuli is enlarged relative to the screen size (i.e., they are not presented to scale) to ease visualization of the conditions for the reader; refer to Figure 6 for an accurate depiction of the size of stimuli in proportion to screen size.

Experiment 2B. All aspects of the design of Experiment 2B were the same as Experiment 2A with the exception of the following. Rather than the consistency of mapping of spatial location to task as in Experiment 2A, the validity of the cue in relation to the location of the following single item was manipulated here in Experiment 2B. On 80% of the trials the fixation cross cue was valid—the single item appeared on the same side as the fixation cross cue. On 20% of the trials the fixation cross cue was invalid—the single item appeared on the side opposite to the fixation cross cue. The following search display always appeared on the side opposite to the single item on both valid and invalid trials. All possible trial conditions generated by combining these independent variables are illustrated in Figure 9.

Figure 9.

Trial Types in Experiment 2B



Validity	valid	invalid	valid	invalid
Single Item Response	"top"	no response	no response	"top"
Search Relevance	relevant	irrelevant	irrelevant	relevant
Preparation–Search	match	match	mismatch	mismatch

Note. The trials depicted here assumed that participants responded only to blue single items. For participants who responded only to orange single items, blue single items would be replaced by orange single items in the figure above. The size of the diamond stimuli is enlarged relative to the screen size (i.e., they are not presented to scale) to ease visualization of the conditions for the reader; refer to Figure 7 for an accurate depiction of the size of stimuli in proportion to screen size.

Results

Only correct responses to the single item task were included in single item response time (RT) analyses, and only correct responses to the search task after a correct response to the single item were included in search RT analyses. We then excluded from analyses all trials with RTs below 200 ms or above 3000 ms (~0.1% of data in both experiments), as they were unlikely to reflect task-relevant processes (Miller, 2023). Also, the first block of 120 trials was treated as practice and excluded from analysis as per our power analysis, however the appendix includes analyses involving all three blocks. Mean RTs were then computed based on the remaining observations.

Single Item Task Performance

Experiment 2A. Participants demonstrated high overall accuracy in responding selectively based on colour to the single item ($M_{\text{hit minus false alarm}}$ = 96.2%). Mean discrimination accuracy on trials that required a response was 98.7%. An independent samples t-test was conducted to compare mean single item RTs between the consistent (M = 563 ms, SD = 74.1 ms) and random (M = 596 ms, SD = 50.6 ms) conditions. Participants in the consistent condition responded significantly faster (33 ms) to the single item than participants in the random condition, $t(61.84) = 2.21$, $p = .031$.

Experiment 2B. Participants demonstrated high overall accuracy in responding selectively based on colour of the single item ($M_{\text{hit minus false alarm}}$ = 96.6%). Mean discrimination accuracy on trials that required a response was 98.9%. A paired sample t-test was conducted to compare mean single item RTs between valid (M = 571 ms, SD = 61.6 ms) and invalid (M = 622 ms, SD = 60.7 ms) trials. Response times to the single item in valid trials were significantly faster (51 ms) than response times to the single item in invalid trials, $t(31) = 7.81$, $p < .001$.

Search Task Performance

Experiment 2A. Mean search RTs and corresponding error rates were submitted to mixed factor analyses of variance (ANOVA) that treated preparation–search (match/mismatch) and search relevance (relevant/irrelevant) as within-subjects variables and condition (consistent/random) as a between-subjects variable. An alpha level of .05 was used to determine statistical significance. Mean search RTs and corresponding error rates for all conditions are shown in Table 2. Mean search RTs collapsed across search relevance are displayed in Figure 10. The pattern of data in Figure 10 suggests that there was a strong preparation–search match effect, but that this effect does not appear to differ across consistent and random conditions. These observations are supported by the analyses described below.

Table 2

Mean RTs and Error Rates in Experiment 2A

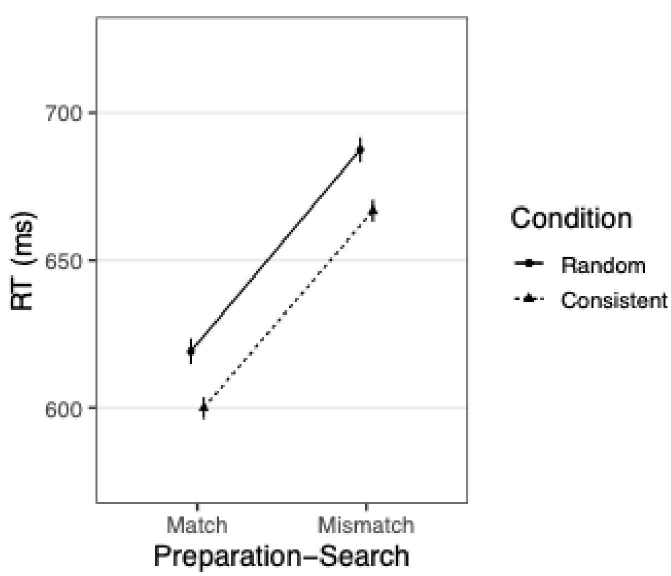
Note. Standard deviations are presented in parentheses. The mean response times and error

	Search Irrelevant				Search Relevant			
	Match		Mismatch		Match		Mismatch	
	RT	Err Rate	RT	Err Rate	RT	Err Rate	RT	Err Rate
Consistent	609 (64.9)	3.01 (2.84)	661 (74.7)	2.50 (3.05)	591 (63.1)	2.83 (2.70)	672 (73.0)	3.14 (3.98)
Random	624 (63.5)	2.04 (2.46)	687 (77.4)	2.74 (2.29)	614 (67.8)	2.33 (2.71)	688 (75.5)	3.23 (2.56)

rates by condition from blocks two and three (see appendix for all three blocks).

Figure 10

Mean RTs to Search Targets in Experiment 2A: Condition by Preparation–Search



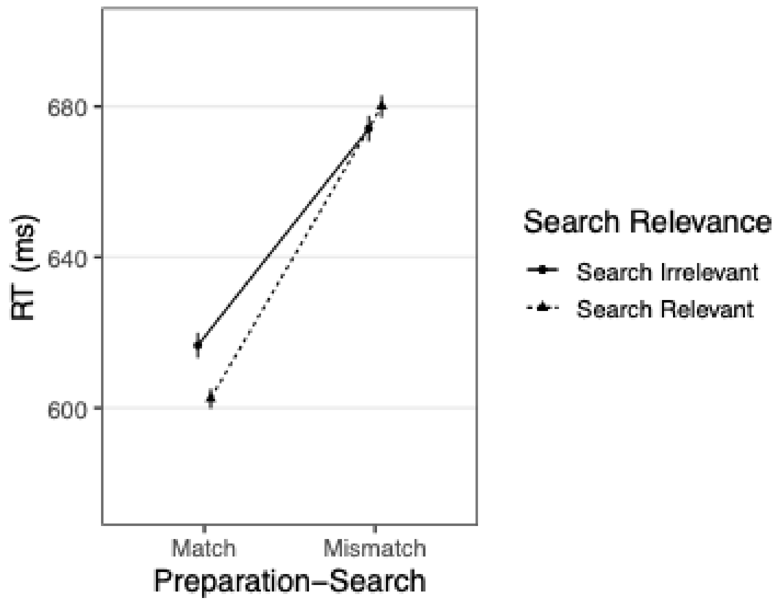
Note. Mean RTs in the search task collapsed across search relevance. Error bars depict the standard error of the mean adjusted to eliminate between-subjects variability (Cousineau, 2005; Morey, 2008).

The analysis revealed a significant main effect of preparation–search, $F(1,70) = 283.85$, $p < .001$, $\eta_p^2 = .802$. Search responses were 67 ms faster when the colour of the search target matched the colour prepared for in the single item task (M = 610 ms, SD = 65.3 ms) than when the colour of the search target mismatched the colour prepared for in the single item task (M = 677 ms, SD = 75.2 ms). Most important, the interaction between condition and preparation–search was clearly not significant, $F(1,70) = 0.04$, $p = .849$, $\eta_p^2 < .001$; the preparation–search match effect did not differ across the consistent and random conditions.

There was a significant interaction between preparation–search and search relevance, $F(1,70) = 18.17$, $p < .001$, $\eta_p^2 = .206$. Follow-up simple effects analyses were conducted to examine the effect of search relevance within each level of preparation–search. On preparation–search match trials, participants responded significantly faster when the single item was search relevant (M = 602, SE = 7.71) than when the single item was search irrelevant (M = 617, SE = 7.57), $t(70) = 4.18$, $p < .001$. On preparation–search mismatch trials, the difference in response times between search relevant and search irrelevant trials was not significant, $t(70) = -1.56$, $p = .124$. These simple effects analyses revealed that the effect of search relevance was significant on preparation–search match trials, but not significant on preparation–search mismatch trials; see Figure 11.

Figure 11

Mean RTs to Search Targets in Experiment 2A: Search Relevance by Preparation–Search



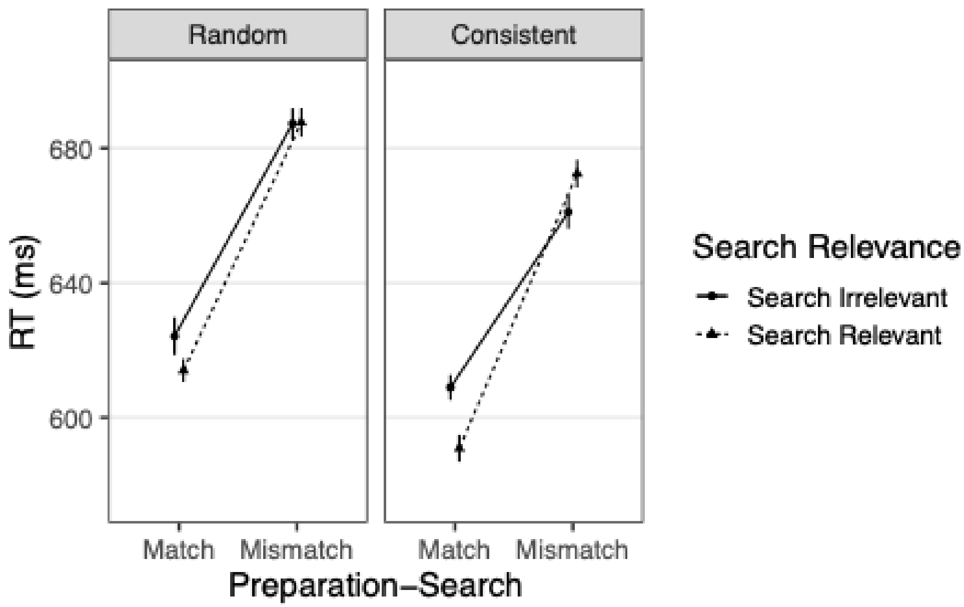
Note. Mean RTs in the search task collapsed across condition. Error bars depict the standard error of the mean adjusted to eliminate between-subjects variability (Cousineau, 2005; Morey, 2008).

Further, this interaction between preparation–search and search relevance differed across condition, $F(1,70) = 4.08$, $p = .047$, $\eta_p^2 = .055$. To decompose this three-way interaction, the size of the preparation–search match effect was compared across search relevant and irrelevant trials, separately for the consistent and random conditions. For participants in the consistent condition, the preparation–search match effect was larger on search relevant trials (81 ms) than search irrelevant trials (52), $t(70) = -4.44$, $p < .001$. For participants in the random condition, there was no significant difference in the preparation–

search match effect between search relevant (74 ms) and irrelevant trials (63 ms), $t(70) = -1.59$, $p = .117$. These analyses demonstrate that the effect of search relevance on the preparation–search match effect was significant for participants in the consistent condition, but not for participants in the random condition (see Figure 12).

Figure 12

Mean RTs to Search Targets in Experiment 2A: 3-Way Interaction



Note. Mean RTs in the search task. Error bars depict the standard error of the mean adjusted to eliminate between-subjects variability (Cousineau, 2005; Morey, 2008).

The analysis of search task error rates did not reveal any significant effects. However, the interaction between condition and preparation–search approached significance, $F(1,70) = 3.41$, $p = .069$, $\eta_p^2 = .046$. Though not significant, this effect provides modest evidence that aligns with our hypothesis that the preparation–search effect is smaller for the consistent condition than the random condition. We discuss this pattern of error rates further in the discussion.

Experiment 2B. Mean search RTs and corresponding error rates were submitted to repeated measures analyses of variance (ANOVA) that treated validity (valid/invalid), preparation–search (match/mismatch), and search relevance (relevant/irrelevant) as within-subjects variables. An alpha level of .05 was used to determine statistical significance. Mean search RTs and corresponding error rates are shown in Table 3. Mean search RTs collapsed across search relevance are displayed in Figure 13. The pattern of data in Figure 13 suggests that there was a strong preparation–search effect, but that this effect does not appear to differ across valid and invalid trials. These observations are supported by the analyses described below.

Table 3

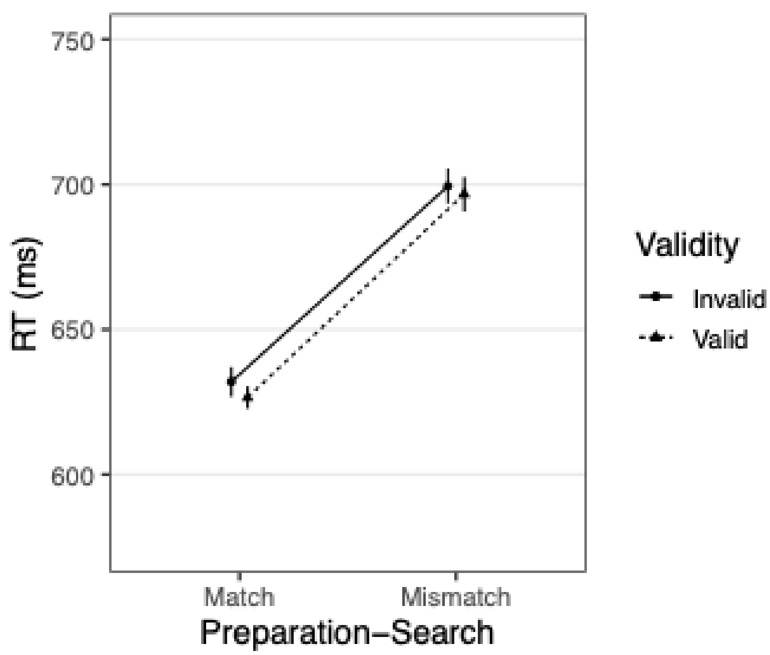
Mean RTs and Error Rates in Experiment 2B

	Search Irrelevant				Search Relevant			
	Match		Mismatch		Match		Mismatch	
	RT	Err Rate	RT	Err Rate	RT	Err Rate	RT	Err Rate
Valid	635 (78.5)	1.94 (2.69)	693 (92.0)	3.21 (4.17)	618 (79.4)	3.20 (4.39)	700 (97.9)	5.05 (5.20)
Invalid	643 (87.0)	2.65 (5.51)	685 (102)	4.35 (6.27)	621 (81.9)	2.57 (4.79)	703 (81.5)	4.42 (11.8)

Note. Standard deviations are presented in parentheses. The mean response times and corresponding error rates by validity from blocks two and three (see appendix for all three blocks).

Figure 13

Mean RTs to Search Targets in Experiment 2B: Validity by Preparation–Search



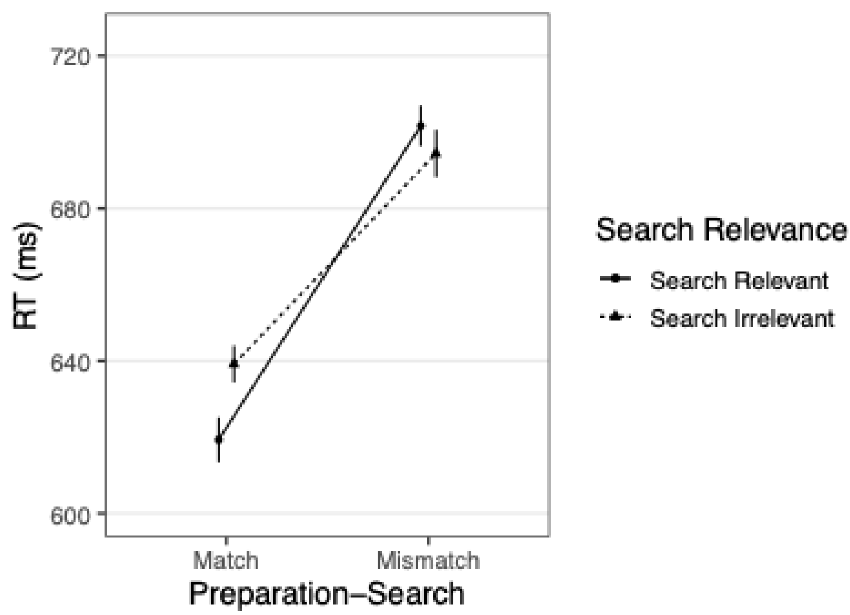
Note. Mean RTs in the search task collapsed across search relevance. Error bars depict the standard error of the mean.

The analysis revealed a significant main effect of preparation–search, $F(1,31) = 151.39$, $p < .001$, $\eta_p^2 = .830$. Search responses were 69 ms faster when the colour of the search target matched the colour prepared for in the single item task (M = 629 ms, SD = 81.5 ms) than when the colour of the search target mismatched the colour prepared for in the single item task (M = 698 ms, SD = 92.5 ms). Most important, the interaction between validity and preparation–search was clearly not significant, $F(1,31) = 0.06$, $p = .802$, $\eta_p^2 = .002$; the preparation–search match effect did not differ across valid and invalid trials.

There was a significant interaction between preparation–search and search relevance, $F(1,31) = 12.77$, $p = .001$, $\eta_p^2 = .292$. Therefore, follow-up simple effects analyses were conducted to examine the effect of search relevance within each level of preparation–search. On preparation–search match trials, participants responded significantly faster to the search target when the single item was search relevant (M = 619, SE = 13.9) than when the single item was search irrelevant (M = 639, SE = 14.2), t(31) = -2.70, p = .012. On preparation–search mismatch trials, the difference in response times to the search target between search relevant and search irrelevant trials was non-significant, t(31) = .865, p = .394. These simple effects analyses revealed that the effect of search relevance was significant on preparation–search match trials, but not significant on preparation–search mismatch trials; see Figure 14.

Figure 14

Mean RTs to Search Targets in Experiment 2B: Search Relevance by Preparation–Search



Note. Mean RTs in the search task collapsed across validity. Error bars depict the standard error of the mean.

The analysis of search task error rates also revealed a significant main effect of preparation–search, $F(1,31) = 11.05$, $p = .002$, $\eta_p^2 = .263$. This effect was similar to the corresponding effect in the search RT analysis, with lower error rates for the match trials than for mismatch trials (refer to Table 3). The interaction between validity and preparation–search was not significant, $F(1,31) = 0.28$, $p = .599$, $\eta_p^2 < .009$.

Discussion

The results from both Experiments 2A and 2B reflect successful replications of the preparation–search match effect reported by Sclodnick et al. (2024). Specifically, participants responded faster to search targets when the search target colour matched the colour prepared for in the single item task, than when the search target colour mismatched the colour prepared for in the single item task.

In Experiment 2A, the primary aim was to determine whether this preparation–search match effect is sensitive to associative learning processes thought to bind task sets to spatial contexts. The results of the RT analyses failed to provide evidence for such an effect—consistency of mapping of single item and search tasks to spatial locations did not influence the preparation–search match effect. Although the pattern of error rates in Experiment 2A did produce an interaction that aligned with the associative learning proposal, the key interaction fell short of statistical significance. Moreover, there was no hint of this interaction in the error rates in Experiment 1. As such, we conclude that the error rate pattern in Experiment 2A is not replicable and most likely spurious. All told, the results fail to support the proposal that the preparation–search match effect depends on associative learning processes that mediate the efficiency of task set switching between the single item and search tasks.

In Experiment 2B, the aim was to determine whether the preparation–search match effect is sensitive to endogenous cueing of the location of the single item; that is, cueing that allowed participants to strategically shift attention to the likely location of the single item prior to its onset. Although the cueing manipulation was successful in producing faster response times to validly cued single items than to invalidly cued single items, validity had no effect on participants' performance in the search task. In particular, the preparation–search match effect did not differ for valid and invalid trials, indicating that endogenous shifts of attention to the single item prior to its onset did not influence the processes responsible for the preparation–search match effect.

Although not of primary interest at the outset of the study, the results did reveal a conceptually important finding in both Experiments 2A and 2B. In particular, the search relevance of the single item (blue/orange vs. green) did significantly impact the preparation–search match effect in both Experiments 2A and 2B. The preparation–search match effect was larger for search relevant (blue/orange) single items than for search irrelevant (green) single items. Subsequent analyses demonstrated that this effect owed to participants being faster to respond to search targets on match trials when they had just responded to a single item that matched the search target colour than when they had just ignored a green single item. This finding points to the idea that the preparation–search match effect depends on representations that result from an interaction between attentional preparation and single item processing that carries over to search, rather than on representations that result from preparatory processes alone. This issue is discussed further in the General Discussion.

General Discussion

Prior studies of visual search indicate that both bottom-up salience and memory related to prior acts of attention influence pop-out search (Maljkovic & Nakayama, 1994; Awh et al., 2012). However, the nature of the memory representations that contribute to pop-out search is a topic of ongoing study. The method introduced recently by Sclodnick et al. (2024) demonstrates that top-down preparation for a first task can affect goal-related representations which carry over to influence performance on a following search task. This result points to the involvement of memory for goal-directed control processes in pop-out search, and questions a widely held view that the memory contribution to pop-out search is limited to persistence of short-term visual memory representations associated with prior search targets (Theeuwes, 2018). The present study aimed to test this idea further by examining whether the preparation–search match effect of Sclodnick et al. (2024) is subject to associative learning that involves high-level task representations.

Associative Learning and the Preparation–Search Match Effect

The results of Experiment 1 provided a successful replication of the preparation–search match effect. Search task response times were 92 ms faster for match trials than for mismatch trials using the original method reported by Sclodnick et al. (2024). Experiments 2A and 2B provided successful replications of the preparation–search match effect using an altered method that measured the attending component of the effect. In these experiments, the response time difference between match and mismatch trials was slightly smaller than in Experiment 1 (Exp. 2A: 67 ms, Exp 2B: 69 ms), as this altered method measures only one of two components (the attending component) of the original preparation–search match effect.

In all, the results of the three experiments demonstrate that the preparation–search match effect of Sclodnick et al. is robust and highly replicable.

Experiments 1 and 2A introduced spatial separation of the single item and search tasks to investigate the role of contextual overlap in the preparation–search match effect. Past experiments have shown that associating task sets with separate spatial locations can lead to more effective task-switching, and thus smaller task-switch costs (Crump et al., 2006; Leboe et al., 2008; Mayr and Bryck, 2007). Our hypothesis was that carryover of preparation from the single item task to search task would be reduced through associative learning. Such a reduction in the carryover of single item task processing to search task processing would presumably reduce the preparation–search match effect. However, in both experiments the preparation–search match effect was equal in magnitude in the consistent and random spatial mapping conditions. Therefore, results from our experiments failed to support the idea that location-specific associative learning would reduce the preparation–search match effect.

Experiment 2B was conducted as a control experiment that addressed whether endogenous spatial orienting to the spatial location of the single item would influence the preparation–search match effect. This experiment was successful in producing an endogenous orienting effect, as response times to the single item were faster for valid trials than for invalid trials. However, the validity of the single item did not impact the preparation–search match effect. The results of Experiment 2B therefore suggest that more efficient engagement of a first task set for valid single item trials did not affect the efficiency of switching to a second task set for search. However, once again the results of this experiment demonstrate the robustness and replicability of the preparation–search match effect.

The Effect of Single Item Colour on Search

Experiments 2A and 2B revealed an interesting finding regarding the search relevance of the single item colour. There was a larger preparation–search match effect for search relevant single items than for search irrelevant single items. In other words, participants were faster to respond to search targets on match trials when they had just responded to a single item that matched the search target colour, than when they had just ignored a green single item. This finding points to the idea that the preparation–search match effect depends on representations that result from an interaction between attentional preparation and single item processing that carries over to search—this effect may not rely on representations resulting from preparatory processes alone.

Specifically, participants' preparation for blue single items could be thought of as a task set. One way to think about the preparation–search match effect is that it is the result of preparation carrying over from the single item task to the search task. This preparation hypothesis involves only the preparatory task set in creating a memory representation that facilitates search. A second hypothesis is that the preparation–search match effect is the result of preparation carrying over and interacting with perceptual encoding of the single item. This preparation and selection hypothesis involves both preparatory task set and selection of the single item in creating a memory representation that facilitates search. The two-way interaction between preparation–search and search relevance favours the preparation and selection account.

Now, what are the implications of these two accounts in relation to top-down and bottom-up attentional influences on visual search? The preparation hypothesis could easily be classified as hinging only on top-down processes. However, remember that participants in our experiments prepared for a particular colour repeatedly across a long series of trials. It seems plausible that repeated acts of preparation could ultimately involve an automatic contribution to top-down preparation. Therefore, even the preparation hypothesis likely involves a blend of bottom-up (automatic) and top-down processing. The preparation and selection hypothesis more explicitly involves a blend of bottom-up and top-down processes—a top-down act of preparation could constrain the representation produced when the single item is perceived, selected, and acted upon. In this case, a purely top-down act of preparation influences the memory representation created, which then carries forward in a bottom-up manner (automatically) to influence search. Clearly, both of these hypotheses can be described in terms of bottom-up and top-down processing, though the use of multiple forms of bottom-up processing here constitutes a conceptual challenge. This conceptual challenge has been highlighted in recent discussions of the failed dichotomy between bottom-up and top-down processes (Awh et al., 2012).

Implications and Future Directions

There are two potential explanations as to why we did not find an effect of associative learning of spatial location. First, it is possible that an associative learning effect could occur with our task, but did not occur in the present study because the spatial contexts that we used in our experiments were not sufficiently distinct to allow that associative learning based on task–location consistency to occur. We distinguished the tasks by separating them horizontally on the computer screen, but perhaps this method did not produce two contexts that were sufficiently distinct to afford associative learning involving the task set representations for the single item and search tasks. Future research on this issue could explore separating tasks vertically, such as above and below fixation (Crump et al., 2008;

Leboe et al., 2008). However, it seems unlikely that such a minor difference in method would render different results than the current experiments. A more promising alternative would be to use a more stark contextual distinction, such as having participants attend and respond to the single item on one display monitor, and respond to the search displays on a separate display monitor, thus emphasizing the contextual difference between the two tasks.

A second reason we may not have found an effect of associative learning of spatial location is that the preparation–search match effect may not be due to a task-switching cost. It is possible that the processes on which this effect relies are not susceptible to task-switching principles because they are not purely higher-order processes that rely on top-down goals and memory of prior preparation. According to this alternative proposal, and as described in the above section, the carryover effect from single item to search task may be driven, at least in part, by the influence of attention to the single item on lower-level attentional guidance mechanisms that influence subsequent search. Lamy et al. (2010) proposed a dual-stage account of pop-out search that includes both higher level post-perceptual representations as well as low-level perceptual representations. It is possible the preparation–search match effect fits into this account.

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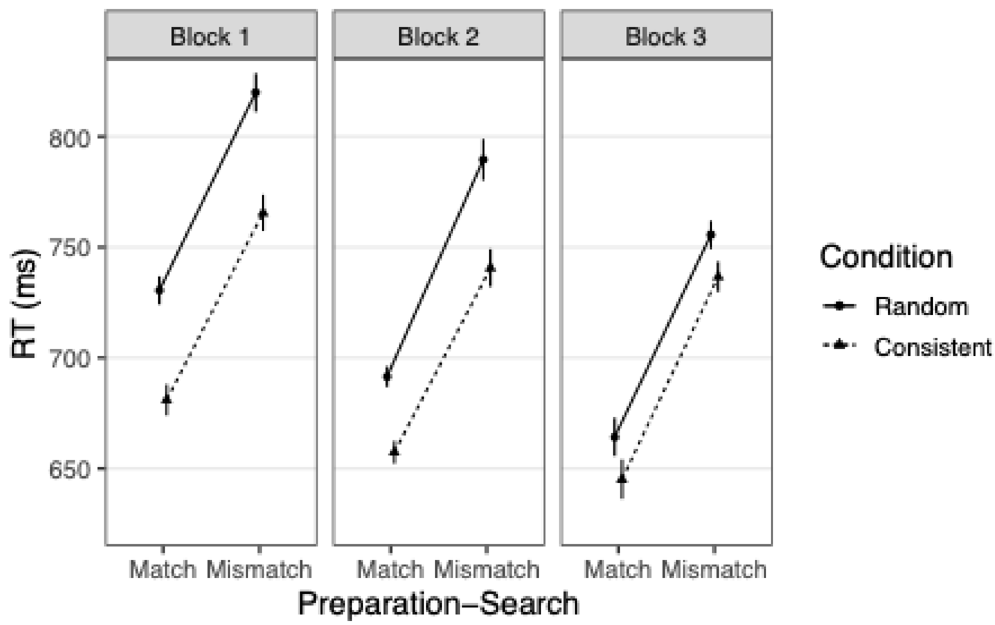
Appendix

Experiment 1 Analyses

Figure 1

Mean RTs to Search Targets in Experiment 1 Across all Blocks



Note. Mean RTs in the search task across all three blocks (120 trials each). Error bars depict the standard error of the mean adjusted to eliminate between-subjects variability (Cousineau, 2005; Morey, 2008). There was a significant main effect of preparation–search, $F(1,70) = 223.6$, $p < .001$, $\eta_p^2 = .762$. There was no significant interaction between preparation–search and condition, $F(1, 70) = .30$, $p = .588$, $\eta_p^2 = .004$ and this interaction did not emerge across block, $F(2, 139.70) = .81$, $p = .448$, $\eta_p^2 = .011$.

Table 1

Mean RTs and Standard Deviations in Experiment 1

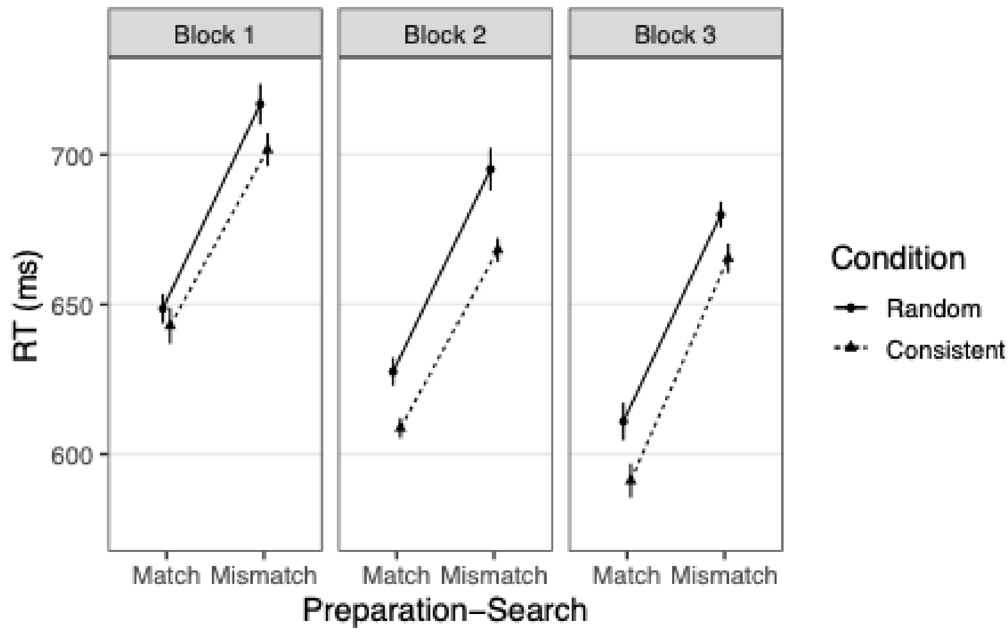
Block	Condition	Feature Rep.	Prep.–Search	Mean RT (ms)	Error Rate
1	Consistent	Switch	Match	681 (70.5)	.947 (1.92)
			Mismatch	765 (103.3)	2.82 (3.26)
		Repeat	Match	681 (66.3)	1.26 (2.23)
			Mismatch	766 (113.7)	2.27 (2.97)
	Random	Switch	Match	717 (72)	1.63 (3.16)
			Mismatch	823 (119.9)	3.38 (5.59)
		Repeat	Match	744 (88.1)	.778 (1.69)
			Mismatch	817 (98.4)	2.39 (4.86)
2	Consistent	Switch	Match	654 (77.2)	1.31 (1.84)
			Mismatch	741 (118.7)	3.11 (3.43)
		Repeat	Match	661 (78.5)	1.36 (2.25)
			Mismatch	740 (121.5)	2.24 (3.21)
	Random	Switch	Match	687 (83.8)	1.12 (2.53)
			Mismatch	793 (126.6)	2.69 (2.93)
		Repeat	Match	696 (86.4)	1.61 (2.21)
			Mismatch	786 (103.9)	2.34 (3.10)
3	Consistent	Switch	Match	649 (79.3)	1.68 (2.19)
			Mismatch	739 (110.4)	2.92 (4.26)
		Repeat	Match	642 (77.9)	1.62 (2.24)
			Mismatch	734 (107.3)	2.15 (2.95)
	Random	Switch	Match	658 (69.1)	2.00 (3.42)
			Mismatch	767 (97.5)	2.71 (3.38)
		Repeat	Match	671 (73.9)	2.01 (3.59)
			Mismatch	744 (83.3)	3.10 (4.26)

Note. Standard deviations are presented in parentheses. The mean response times and error rates for all three blocks.

Experiment 2A Analyses

Figure 2

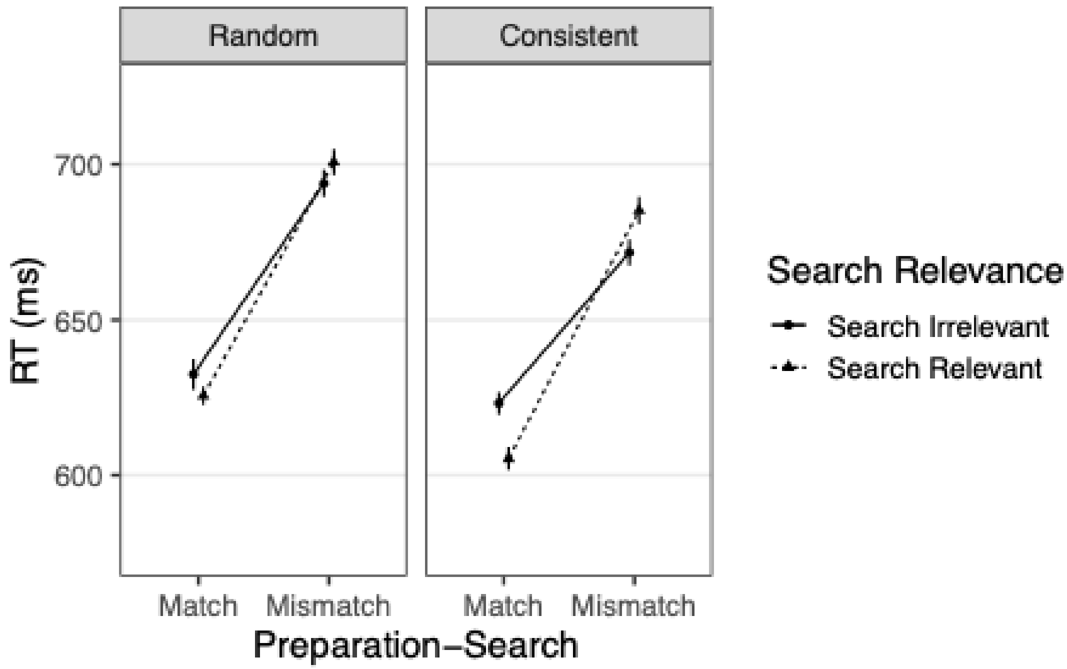
Mean RTs to Search Targets in Experiment 2A Across all Blocks



Note. Mean RTs in the search task across all three blocks (120 trials each). Error bars depict the standard error of the mean adjusted to eliminate between-subjects variability (Cousineau, 2005; Morey, 2008). There was a significant main effect of preparation–search, $F(1, 70) = 322.13$, $p < .001$, $\eta_p^2 = .821$. There was no significant interaction between preparation–search and condition, $F(1, 70) = 0.32$, $p = .575$, $\eta_p^2 = .005$ and this interaction did not emerge across block, $F(1.99, 139.52) = 1.89$, $p = .156$, $\eta_p^2 = .026$.

Figure 3

Mean RTs to Search Targets in Experiment 2A 3-Way Interaction



Note. Mean RTs in the search task from all three blocks. Error bars depict the standard error of the mean adjusted to eliminate between-subjects variability (Cousineau, 2005; Morey, 2008). There was a significant three-way interaction between condition, preparation–search, and search relevance, $F(1, 70) = 5.10$, p = .027, $\eta_p^2 = .068$. Follow-up analyses revealed that the effect of search relevance on the preparation–search match effect was significant for participants in the consistent condition, but not for participants in the random condition. Specifically, for participants in the consistent condition, the preparation–search match effect was larger on search relevant trials (80 ms) than search irrelevant trials (49), $t(70) = -5.66$, $p < .001$.

Table 2

Mean RTs and Standard Deviations in Experiment 2A

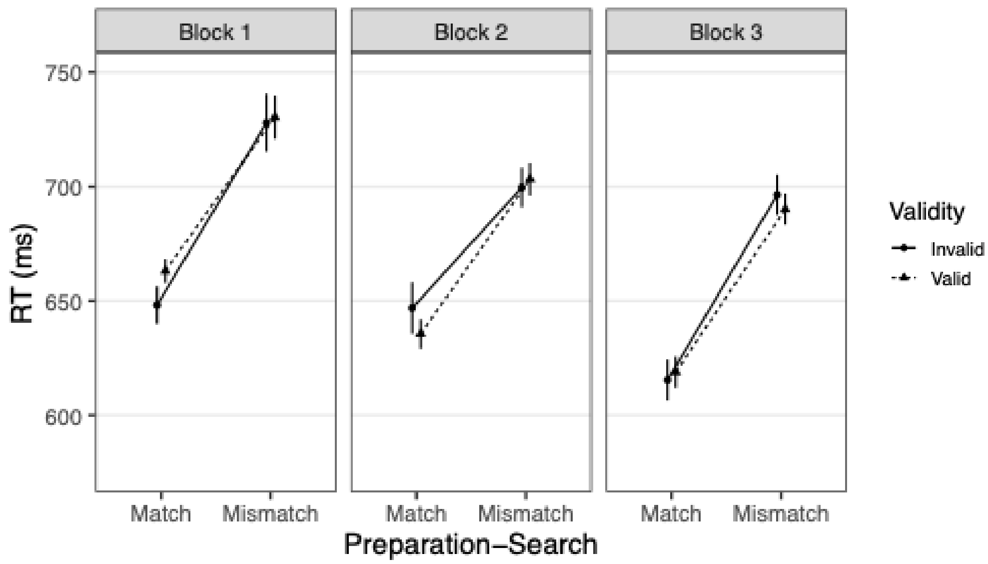
Block	Condition	Search Relevance	Prep.–Search	Mean RT	Error Rate
1	Consistent	Irrelevant	Match	652 (100.5)	2.15 (3.85)
			Mismatch	693 (89.2)	3.06 (4.60)
		Relevant	Match	634 (92.8)	2.46 (4.08)
			Mismatch	710 (102.4)	3.25 (4.41)
	Random	Irrelevant	Match	649 (65.6)	1.69 (3.17)
			Mismatch	707 (88.9)	1.86 (2.32)
		Relevant	Match	648 (70.2)	2.76 (2.92)
			Mismatch	726 (90.2)	2.58 (3.18)
2	Consistent	Irrelevant	Match	618 (67.3)	3.15 (3.47)
			Mismatch	662 (75.4)	2.41 (3.26)
		Relevant	Match	600 (68.6)	3.15 (4.05)
			Mismatch	674 (75.2)	3.41 (5.48)
	Random	Irrelevant	Match	632 (75.1)	1.95 (3.32)
			Mismatch	694 (90.4)	2.69 (2.85)
		Relevant	Match	623 (79.0)	2.01 (2.79)
			Mismatch	696 (93.8)	3.53 (3.04)
3	Consistent	Irrelevant	Match	600 (68.0)	2.88 (4.00)
			Mismatch	660 (78.3)	2.59 (4.15)
		Relevant	Match	582 (59.6)	2.52 (2.91)
			Mismatch	671 (76.9)	2.84 (3.57)
	Random	Irrelevant	Match	616 (59.3)	2.13 (2.54)
			Mismatch	680 (70.7)	2.79 (2.93)
		Relevant	Match	605 (64.5)	2.66 (3.58)
			Mismatch	680 (67.8)	2.97 (3.22)

Note. Standard deviations are presented in parentheses. Table depicts mean response times and corresponding error rates for all three blocks.

Experiment 2B Analyses

Figure 4

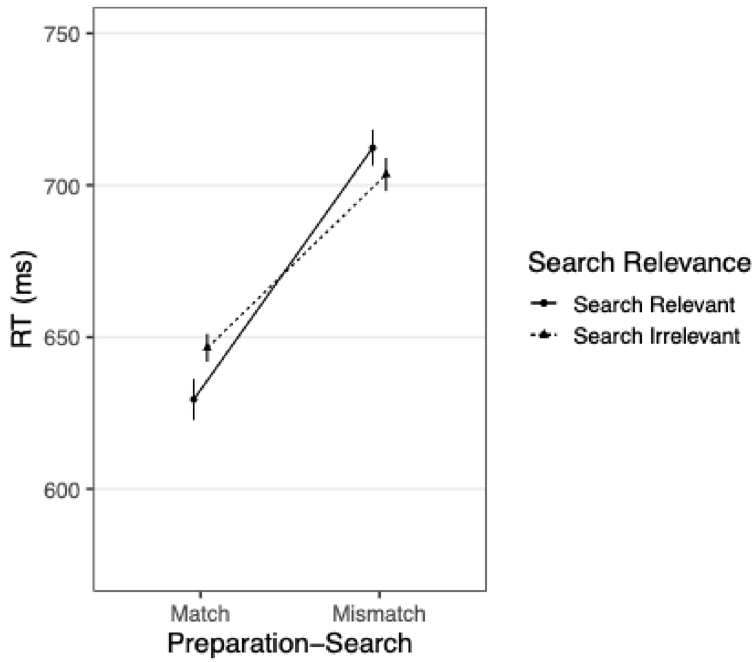
Mean RTs to Search Targets in Experiment 2B Across all Blocks



Note. Mean RTs in the search task across all three blocks (120 trials each). Error bars depict the standard error of the mean adjusted to eliminate between-subjects variability (Cousineau, 2005; Morey, 2008). There was a significant main effect of preparation–search, $F(1, 31) = 106.67$, $p < .001$, $\eta_p^2 = .775$. There was no significant interaction between preparation–search and validity, $F(1, 31) = 1.10$, $p = .749$, $\eta_p^2 = .003$, and this interaction did not emerge across block, $F(1.68, 51.94) = 0.80$, $p = .436$, $\eta_p^2 = .025$.

Figure 5

Mean RTs to Search Targets in Experiment 2B Across Search Relevance



Note. Mean RTs in the search task from all three blocks. Error bars depict the standard error of the mean adjusted to eliminate between-subjects variability (Cousineau, 2005; Morey, 2008). There was a significant interaction between preparation–search and search relevance, $F(1, 31) = 11.23$, p = .002, $\eta_p^2 = .266$. Follow-up simple effects analyses revealed that on preparation–search match trials, participants responded significantly faster when the single item was search relevant (M = 629, SE = 13.1), then when the single item was search irrelevant, (M = 649, SE = 13.9), $t(31) = -2.27$, $p = .030$.

Table 3

Mean RTs and Standard Deviations in Experiment 2B

Block	Validity	Search Relevance	Prep.–Search	Mean RT (ms)	Error Rate
1	Invalid	Irrelevant	Match	652 (94.9)	2.81 (6.67)
			Mismatch	720 (102.9)	3.49 (8.62)
		Relevant	Match	644 (78.3)	2.29 (6.19)
			Mismatch	735 (147.7)	3.02 (8.77)
	Valid	Irrelevant	Match	672 (92.9)	2.18 (4.11)
			Mismatch	727 (95.1)	3.88 (5.81)
		Relevant	Match	654 (84.4)	4.01 (4.61)
			Mismatch	734 (100.2)	5.12 (5.28)
2	Invalid	Irrelevant	Match	662 (116)	2.46 (9.36)
			Mismatch	695 (119)	3.70 (8.98)
		Relevant	Match	631 (103)	2.16 (7.80)
			Mismatch	705 (95.1)	3.85 (11.3)
	Valid	Irrelevant	Match	650 (88.6)	2.38 (3.26)
			Mismatch	704 (101)	3.55 (5.45)
		Relevant	Match	621 (82.3)	3.50 (5.66)
			Mismatch	703 (105)	5.77 (5.97)
3	Invalid	Irrelevant	Match	619 (93.4)	2.60 (7.46)
			Mismatch	693 (106)	5.21 (8.51)
		Relevant	Match	611 (81.6)	2.92 (6.92)
			Mismatch	699 (90.1)	5.10 (14.2)
	Valid	Irrelevant	Match	622 (82.8)	1.47 (3.42)
			Mismatch	683 (93.2)	2.76 (4.51)
		Relevant	Match	615 (85.1)	2.94 (3.87)
			Mismatch	698 (97.0)	4.31 (5.82)