Practice reduces set-specific capture costs only superficially

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Abstract

Contingent attentional capture costs are doubled or tripled under certain conditions when multiple attentional sets guide visual search (e.g., “search for green letters” and “search for orange letters”). Such “set-specific” capture occurs when a potential target that matches one attentional set (e.g., a green stimulus) impairs the ability to identify a temporally proximal target that matches another attentional set (e.g., an orange stimulus). In the present study, we examined whether these severe set-specific capture effects could be attenuated through training. In Experiment 1, half of participants experienced training consisting of mostly trials involving a set switch from distractor to target, while the other half experienced training consisting of mostly trials in which a set switch was not required. Upon test, participants trained on set switches produced greatly reduced set-specific capture effects compared to their own pretraining levels and compared to participants trained on trials without a set switch. However, in Experiments 2 and 3, we found that these training effects did not transfer to a new color context or even a single new target color, indicating that they were specific and involved low-level associative learning. We concluded that set-specific capture is pervasive and largely immutable, even with practice.

Keywords Attentional capture · Set-specific capture · Practice effects · RSVP · Visual search · Multitasking · Distraction

Particularly in today’s world of constant connectedness, people are always looking for ways to save time, often by completing more than one task simultaneously. However, multitasking usually comes at a cost due to limitations in our processing systems. Attention is the primary way we manage these processing limitations, by selecting relevant information and inhibiting irrelevant information so that we can accomplish our goals (Corbetta & Shulman, 2002; Desimone & Duncan, 1995; Hopfinger, Buonocore, & Mangun, 2000).

In the case of contingent attentional capture, the act of selecting relevant information can lead to performance costs, when distracting information bears resemblance to targets and then captures one’s attention. For example, in a typical visual search task, participants are given a search goal and must detect or identify any target matching that goal while ignoring distracting visual information (Wolfe, 1994). If the goal is to find any red letter in a display, then participants might adopt an

“attentional set”—a bias in signal processing—for the color red. In a search for red letters, a red number may capture attention and cause the participant to slow her search. In this case, the distractor has been erroneously selected for a deeper level of processing that occurs serially, thereby causing the search to slow down (Treisman & Gelade, 1980), or for the participant to miss targets (Folk, Leber, & Egeth, 2002; Serences et al., 2005). Contingent attentional capture occurs when searching for targets based on basic features such as color, orientation, and motion (Folk, Remington, & Johnston, 1992; Folk, Remington, & Wright, 1994; Harris, Remington, & Becker, 2013). It also occurs with more complex features such as semantic meaning (Ito & Kawahara, 2016), conceptual categories (Wu, Liu, & Fu, 2016), and even temporal order (Born, Kerzel, & Pratt, 2015).

Several studies have recently demonstrated that contingent attentional capture effects can be especially pronounced when we search for more than one item at a time (Adamo, Wozny, Pratt, & Ferber, 2010; Barrett & Zobay, 2014; Dombrowe, Donk, & Olivers, 2011; Grubert & Eimer, 2013, 2016; Ito & Kawahara, 2016; Kawahara & Kumada, 2016; Moore & Weissman, 2010, 2011, 2014; Stroud, Menneer, Cave, & Donnelly, 2012). Searching for more than one item at a time is a situation we might commonly find ourselves in. For example, at the grocery store, you usually search for a handful of items on your list at once. Under some circumstances, this

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type of task can be completed with ease and little cost, especially compared with the cost of adding visual information to a display (e.g., more items in the grocery store; Beck, Hollingworth, & Luck, 2012; Irons & Leber, 2016; Moore & Weissman, 2010; Wolfe, 2012). However, in the presence of distraction or some other kind of task switch, the costs of multitasking in visual search are apparent (Dombrowe et al., 2011; Moore & Weissman, 2010, 2011, 2014).

Moore and Weissman (2010) identified a phenomenon called “set-specific capture” that describes an especially dramatic cost associated with maintaining more than one attentional set (e.g., “search for green letters” and “search for red letters”) under conditions of distraction. Participants searched a rapid serial visual presentation (RSVP) display for two colors of letters, while occasional colored letters appeared peripherally. Performance dropped precipitously when a peripheral distractor matching one of the searched attentional sets (e.g., a green letter) occurred prior to a target matching another of the current attentional sets (e.g., a red letter). The cost in performance, as measured by accuracy to identify targets, tends to be at least two times as large as traditional contingent attentional capture (e.g., the presence of a red digit drawing attention from a red letter on the same trial). We called this “set-specific capture” because attention has been captured not only by the distractor itself (e.g., the red digit) but also by its corresponding attentional set (“search for red letters”), presumably at the cost of maintaining other concurrent attentional sets. We showed that although multiple attentional sets can be maintained at once (even, in fact, without perceptible search costs when distractors are *not* present; Moore & Weissman, 2010, Experiment 1), only a single attentional set can be focused on, or enhanced, at one time (Moore & Weissman, 2010, 2011, 2014). This automatic enhancement occurs when the participant is attending to and deeply processing a distractor or target. Follow-up studies testing this “focus of attention” model confirm that it is limited to a single item and that the processing limitation resembles a bottleneck (Moore & Weissman, 2011, 2014).

Given how ubiquitous multiple-item searches are and how costly set-specific capture is, it would be useful to investigate whether we can reduce or eliminate set-specific capture. In a prior investigation, we showed that this can be done by enhancing the target’s attentional set *prior* to distraction within a trial (Moore & Weissman, 2011). Other studies have shown that traditional attentional capture costs can be modified through practice, experience, and reward/incentives (Anderson, Laurent, & Yantis, 2011; Leber, Kawahara, & Gabari, 2009; Muller, Geyer, Zehetleitner, & Krummenacher, 2009; Thompson, Underwood, & Crundall, 2007; Vatterott & Vecera, 2012; Zehetleitner, Koch, Goschy, & Müller, 2013). Repeated exposure to a distractor can lead to less attentional capture, suggesting the participant acquires the ability to suppress the distractor (Vatterott & Vecera, 2012). Practicing using a particular attentional set can also lead to participants

adopting that set when more than one option is available to them (Irons & Leber, 2016; Leber et al., 2009). However, it is not known whether practice has an impact on set-specific capture, and if so, what mechanism drives the practice effects.

In the present study, we investigated whether set-specific capture could be overcome or mitigated through practice, and in doing so we examined the rigidity of the processes involved in set-specific capture. Training regimes for enhancing attention and cognition in general have been met with mixed success. Cognitive control can be consistently improved through directed strategy training (Braver, Paxton, Locke, & Barch, 2009) or extended practice (Paxton, Barch, Storandt, & Braver, 2006). However, despite improved performance on working memory tasks with training, there is minimal evidence for transfer even to similar tasks (Redick, Shipstead, Wiemers, Melby-Lervåg, & Hulme, 2015). Set-specific capture is similar to task-switching in that two attentional sets are maintained and attention shifts between these sets during a trial. In studies training task-switching, both immutable switch costs and malleable mixing costs have been found (Strobach, Liepelt, Schubert, & Kiesel, 2012). There is some evidence for transfer of mixing cost improvements (Korbach & Kray, 2009; Minear & Shah, 2008), but no transfer for switch costs (Minear & Shah, 2008). The variety of results in cognitive training leaves open the possibility that training set switching could alleviate the dramatic costs of set-specific attentional capture.

There are three possible outcomes following the training of set-specific capture. One possibility is that training has no impact on set-specific capture. Such a result would provide support for the idea that set-specific capture involves an automatic (mandatory) transfer of the attentional set into a capacity-limited “focus of attention,” as we have previously claimed (Moore & Weissman, 2010, 2011, 2014). Moreover, this result would suggest that the stages of processing involved are immutable.

A second possibility is that training reduces set-specific capture by improving one’s ability to task-switch. For example, perhaps the transfer of an attentional set into the focus of attention can be sped up through practice. Or, practice may increase the capacity of the focus of attention to include two or more attentional sets. According to this set switching account, participants trained in set-specific capture would experience a reduction in set-specific capture for not only the practiced attentional sets but also for newly introduced attentional sets. This view would be in line with prior work demonstrating that adopting an attentional set through practice leads to abstract learning that is transferrable (Leber et al., 2009). Such a result would also cohere with studies showing some task-switching skills can be improved with practice (Korbach & Kray, 2009; Minear & Shah, 2008).

A third possibility is that training reduces set-specific capture, but that performance improvement is limited to the precise task conditions and stimuli. This account is based off of associative learning, which refers to learning a relationship between two

stimuli or concepts (Le Pelley, 2010). Associative learning has a significant influence on visual search and visual attention (Le Pelley, Mitchell, Beesley, George, & Wills, 2016). For example, targets are more easily detected when they appear in repeated spatial and/or temporal contexts, a phenomenon known as contextual cuing. This is explained by an association between the target and the display context (Chun, 2000; Chun & Jiang, 1998). Sometimes a cue can be learned as a predictor of a subsequent target, and this cue is more prone to capture attention, affecting phenomena such as the attentional blink (Le Pelley, Vadillo, & Luque, 2013; Livesey, Harris, & Harris, 2009; Luck, Vogel, & Shapiro, 1996). A characteristic of associative learning is that when a cue stimulus and/or context changes—sometimes even only very slightly—learning does not transfer (Olson, Jiang, & Moore, 2005; Vatterott & Vecera, 2012). This is because the association is highly stimulus specific. According to this associative learning account, participants trained in set-specific capture would experience reduced set-specific capture for the trained attentional sets, but not for newly introduced attentional sets. The following three experiments aim to distinguish across these possibilities.

Experiment 1

The goal of Experiment 1 was to investigate whether it is possible to reduce set-specific capture through practice. Similar to our previous studies (Moore & Weissman, 2010, 2011, 2014), participants searched within a central RSVP stream for target-colored letters that appeared in either of two possible colors (e.g., green and orange). On some trials, a target letter was preceded by a target-colored distractor that appeared in either of two peripheral RSVP streams. On same-target-colored (STC) trials, the peripheral distractor's color was the same as the subsequent target's color. On different-target-colored (DTC) trials, the distractor's color was a different target color than the subsequent target's color. On non-target-colored (NTC) trials, the peripheral distractor was colored but was not one of the target colors. Traditional attentional capture is measured as the difference in accuracy between NTC and STC trials. Set-specific capture is measured as the difference in accuracy between STC trials and DTC trials.

In the first part of the experiment, half of participants (*Set Switch* training group) experienced DTC trials on 80% of all trials containing target-colored distraction (20% STC trials), whereas the other half of participants (*Repeat* training group) experienced STC trials on 80% of all trials containing target-colored distraction (20% DTC trials). At the end of the experiment, participants completed a test phase, in which they received equal proportions of DTC and STC trials.

If, after training, set-specific capture costs are smaller in the Set Switch group than in the Repeat group, there is evidence of some flexibility in the system. The next question will be what

drives the training-based improvement. If, on the other hand, no such improvement is observed, we can conclude that focus of attention capacity limitations in the system are largely fixed.

Method

Participants

Sixty-two students ages 18 to 30 years, 18 from Yale University and 44 from Elmhurst College, participated in exchange for course credit. All reported normal or corrected vision. To estimate an appropriate sample size, we performed a power calculation based on a pilot version of this study with five participants in each training group, looking at the difference in set-specific capture effects between the Set Switch and Repeat training groups. We estimated that to achieve 80% power, we needed 29 participants per condition. We aimed for just over this number but fell short of it after eliminating eight participants due to poor performance (see Results section).

Participants provided written informed consent before starting the experiment in accordance with the Yale University or Elmhurst College Institutional Review Boards.

Apparatus and stimuli

Colored letter stimuli were displayed on a 24-in. LCD monitor with a 60-Hz refresh rate, controlled by a PC running Windows 7. Psychtoolbox (Brainard, 1997; Kleiner et al., 2007), implemented in MATLAB, displayed the stimuli and collected responses. Participants sat at an unrestricted viewing distance of about 57 cm from the monitor, at which distance 1 cm corresponds to 1° visual angle, and were told to maintain this distance throughout the experiment (they were supervised by the experimenter). The room was kept dark during testing.

Three continuous RSVP streams of letters ($2.07^\circ \times 1.88^\circ$) appeared over a black background. One stream appeared at fixation, and the other two appeared 4.22° to the left and right of fixation. Letters appeared successively in each RSVP stream for 100 ms, followed by a blank gap of 16 ms.

We modeled the colors of our letters according to the “light” color scheme of Moore and Weissman (2010), with slight adjustments to improve visibility. Possible target colors were orange, lavender, and green. Approximately one third of participants within each training group looked for orange and lavender letters; one third looked for lavender and green letters and one third looked for green and orange letters.¹ Most letters appearing in the peripheral RSVP streams were colored gray,

¹ In this experiment and Experiment 3, we made efforts to evenly distribute the number of participants who looked for each combination of colors. However, sometimes the number of participants in each training group did not divide evenly by the number of color combinations. In these cases, the subgroups could be off by one participant. However, separate analyses confirmed that the combination of colors searched for did not have an impact on the results.

whereas the letters appearing in the central stream were colored. Central RSVP “filler” (nontarget) colors were magenta, tan, and turquoise (see Fig. 1 for color wheel and RGB values.) This color scheme aimed to achieve equal overall salience of stimuli through nearly uniform saturation and luminance, an important consideration because capture is influenced by stimulus salience. Moreover, the color scheme ensured that one or more distractor or filler colors separated each of the target colors in color space (D’Zmura, 1991). Thus, participants could only perform the task by maintaining separate independent attentional sets (Bauer, Jolicoeur, & Cowan, 1996; Irons, Folk, & Remington, 2012; Moore & Weissman, 2010; Stroud, Menneer, Cave, Donnelly, & Rayner, 2011). There were no immediate (one frame to the next) color repetitions of filler letters appearing in the central stream.

Procedure and design

Our task was similar to the task we have used previously and other experiments that have used RSVP displays to measure contingent attentional capture (Folk et al., 2002; Moore & Weissman, 2010; Roper & Vecera, 2012; Serences et al., 2005). Participants viewed three RSVP streams and were instructed to look for letters appearing in either of two colors in the central stream while ignoring stimuli in the peripheral streams. See Fig. 2 for a schematic of the task with example conditions. When a target-colored letter appeared in the central RSVP stream, participants were to indicate whether the letter was from the first half of the alphabet (press “J”) or second half of the alphabet (press “K”). Targets and colored peripheral distractors were selected from either the very beginning (A–G except E) or very end (T–Z except W) of the alphabet in order to reduce demands on decision-making.²

Critically, the RSVP streams were continuous, with “filler” letters appearing uninterrupted in each stream between presentations of targets and colored peripheral distractors. These filler letters were any letter of the alphabet except for I, O, E, and W. Because of the continuous presentation, participants were unaware as to when one “trial” (i.e., presentation of a target) ended and the next began, thus generating a low floor for performance (Moore & Weissman, 2010). The first key press logged within 2,200 ms following a target was recorded as the response to that target. We chose this value after analyzing key button responses from similar previous experiments and discovering that the vast majority of responses were made within 750 ms. The time between targets varied randomly from 2,320 to 4,060 ms. Every 32 trials, participants were

² This design was modeled after previous studies. “E” was eliminated because it looked similar to “F,” another target letter. “W” was eliminated because in the font face selected, it took up more horizontal space than other letters, signaling the target.

Fig. 1 Color wheels designating target colors and distractor colors for each experiment. **a** Color wheel and chart for Experiments 1 and 3. In Experiment 1, two of orange, green, or lavender were target colors (counterbalanced across participants). The third color was a distractor appearing in the periphery in the non-target-colored condition. In Experiment 3, two of orange, green, or lavender were target colors during the training phase (counterbalanced across participants). The third color was a new target color that was added to the search set during the transfer phase. In both experiments, the other three colors in the wheel appeared in the central RSVP stream as filler. **b** Color wheels and charts for Experiment 2. In Experiment 2, participants completed the two phases of the experiment (training and transfer) using separate color wheels, with the order counterbalanced across participants. For Color Wheel 1, the target colors were always turquoise and magenta, and letters in the central RSVP appeared in orange, yellow, or periwinkle. For Color Wheel 2, the target colors were always brown and purple, and letters in the central RSVP appeared in red, green, or teal. (Color figure online)

given a self-paced break at which time they were reminded of the target colors.

There were four trial types: (1) target alone (TA); (2) non-target-colored distraction (NTC), in which a letter changes color in the periphery just before the target appears centrally, but the color change is not to one of the target colors; (3) same-target-colored distraction (STC), in which case a colored peripheral distractor appears shortly before a target of the same color; and (4) different-target-colored distraction (DTC), in which case a peripheral distractor appearing before the target is also target-colored, but not the same color as the target on that trial. Distractor items could appear either one frame prior to the target (“lag 1”) or four frames prior to the target (“lag 4”).

Before starting experimental trials, participants completed two stages of practice trials to familiarize

Fig. 2 Task and trial types. Across all experiments, participants searched for target-colored letters (in this example, orange and green) that appeared within a heterogeneously colored central rapid serial visual presentation (RSVP) stream while ignoring occasional colored distractors appearing in two peripheral RSVP streams. In the target alone (TA) condition, the letters in the peripheral RSVP streams were gray leading up to the presentation of the target. For all other trial types, colored peripheral distractors appeared one, three, or four frames prior to the target (one of four frames for Experiment 1; one or three frames for Experiments 2 and 3). In the same-target-colored (STC) condition, the colored distractor was of identical color to the target. In the different-target-colored (DTC) condition, the colored distractor was one of the to-be-searched target colors, but did not share the color of the target on that trial. In the non-target-colored (NTC) condition (Experiment 1 only), the colored distractor did not match either of the target colors. (Color figure online)

themselves with the task and colors. In the first stage of practice (24 trials, 12 TA of each target color), the speed of the display started at 250 ms per item and gradually sped up. Colored boxes indicating the target colors appeared just above the letters for the duration of practice. Also during this time, the experimenter guided the participants through the task and provided feedback on their responses. In the second stage of practice, all trial types were present, and the colored boxes disappeared. The frame rate continued to accelerate until it reached the speed of the main experiment, about 10 trials into the second part of practice. There were 24 trials in the second stage of practice: six each of TA, NTC, STC, and DTC; lags (1 or 4) were selected randomly. The experimenter provided feedback and guidance as needed.

In the main experiment, the participants completed two phases: training and test. Participants were randomly selected to partake in either of two training sessions:

Table 1 Experiment 1 results from four ANOVAs that averaged across both training groups and across all phases of the entire experiment (i.e. training and test phases)

ANOVA design	Factors	Effects	Interactions	Statistics			Descriptives	
				<i>df</i>	<i>F</i>	<i>p</i>	η_p^2	Larger mean (<i>SD</i>)
Trial type (TA, NTC, STC, DTC); lag 1 ONLY	Trial type	Main effects	Trial Type × lag	(3, 162)	34.09	<.001	0.387	Smaller mean (<i>SD</i>)
				(2, 108)	35.16	<.001	0.394	
Trial type (NTC, STC, DTC); lag (1, 4)	Trial type	NO lag	Trial Type × lag	(2, 108)	38.59	<.001	0.417	
				(1, 54)	<1			
Trial type (STC, DTC); lag (1, 4)	Trial type	STC > DTC	Trial Type × lag	(1, 54)	14.14	<.001	0.214	
				(1, 54)	29.94	<.001	0.365	0.663 (0.185)
Trial type (NTC, STC); lag (1, 4)	Trial type	NTC > STC	lag 4 > 1	(1, 54)	35.42	<.001	0.405	0.712 (0.156)
				(1, 54)	9.36	.003	0.153	0.750 (0.141)
				(1, 54)	25.39	<.001	0.328	0.742 (0.133)

Note. The first ANOVA shows a difference across all trial types. Because TA trials do not have distractors, they do not have a lag, so lag 1 data only was included for other trial types in this ANOVA. The second ANOVA uses all trial types except TA and includes lag data. The third ANOVA provides evidence for set-specific capture (STC > DTC), and the fourth ANOVA provides evidence of contingent attentional capture (NTC > STC). For effects that compare two means, the higher mean is listed first, and the smaller mean is listed second. Standard deviations are in parentheses

Repeat training or Set Switch training. Participants in the Set Switch group experienced 60 TA trials, 48 NTC trials, 48 STC trials, and 192 DTC trials. This group was called the Set Switch training group because of the much higher number of DTC trials, in which the distractor and target on a single trial matched different concurrently maintained attentional sets, and accurate performance depended on a successful set switch. In the Repeat training group, the trial distribution was the same except with the numbers of DTC and STC trials swapped. Thus, this group was called the Repeat training group because participants experienced many more STC trials, in which the distractor and target repeated the same color within a trial.

On half of the trials with distraction, the distractor appeared at lag 1. For the other half, the distractor appeared at lag 4; this variable was crossed with target color and trial type. Also, on half of trials with distraction, the target and the distractor appeared from the same part of the alphabet; on the other half of trials they did not. Whether the target and distractor were from the same part of the alphabet was also crossed with the other conditions. Colored distractors appeared on either peripheral display; this occurred randomly (not crossed with the other conditions).

At test, all participants in both training groups experienced 24 TA trials, 24 NTC trials, 24 STC trials, and 24 DTC trials.

Results

Accuracy was the dependent measure on all of our analyses. At the outset we eliminated eight participants (four from each training group) due to poor performance, which was defined as less than 0.5 proportion correct on TA trials across the whole experiment. This cutoff point was based off of prior studies using this task (Moore & Weissman, 2011, 2014). We were left with 27 participants in each group.

Replicating contingent and set-specific capture

We initially collapsed across both phases of the experiment and both training groups in order to examine whether we replicated prior findings of contingent attentional capture and set-specific capture. A repeated-measures ANOVA with the factors trial type (NTC, STC) and lag (1, 4) yielded a main effect of trial type, replicating contingent attentional capture. Another repeated-measures ANOVA with the factors trial type (STC, DTC) and lag (1, 4) yielded a main effect of trial type, replicating set-specific capture. In both ANOVAs, main effects of lag replicated recovery from capture over time (Folk et al., 2002; Moore & Weissman, 2010). Table 1 summarizes statistics from these ANOVAs and two others using the same set of data, each finding a main effect of trial type, consistent with these analyses.

Training effects

We examined the effects of training on set-specific capture using two methods—comparing test performance across training groups and comparing test performance to training phase performance within each training group. See Fig. 3a–d for a breakdown of results by training group, phase, trial type, and lag. Figure 3e and f report the same results, collapsed across lag. For our first analysis using just the test phase data, we examined whether training had an effect on set-specific capture, using a mixed ANOVA with between subjects factor training group (Repeat, Set Switch), and within-subjects factors trial type (STC, DTC) and lag (1, 4). Most critically there was an interaction between training group and trial type, with a greater set-specific capture effect in the Repeat training group ($M = 0.162$) than the Set Switch training group ($M = 0.079$), $F(1, 52) = 4.40$, $p = 0.041$, $\eta_p^2 = 0.145$ (compare STC and DTC trials in Fig. 3e vs. 3f). In spite of this training effect, set-specific capture is still present in the Set Switch training group during test, as it is in the Repeat group. Details from each of these ANOVAs are in Table 2.

Discussion

In Experiment 1, we replicated prior findings of both contingent attentional capture and set-specific capture across both training groups in the experiment as a whole. Importantly, we found practice effects. Practice in the DTC condition in the Set Switch training group led to a reduced (but still present) set-specific capture effect.

Though these results show that set-specific capture can be reduced through practice, it is unknown at what level this learning is occurring. One possibility, which we call the “set switch” hypothesis, is that participants in the Set Switch training group are becoming more efficient at switching away from the enhanced distractor goal to the target. Another possibility, which we call the “associative learning” hypothesis, is that participants in the Set Switch training group are learning specific, low-level connections between the trained colors.

Experiment 2

We designed Experiment 2 to distinguish between the set switch and associative learning hypotheses. Participants performed the same task as in Experiment 1, with the same two training groups (Set Switch and Repeat). However, at test, participants were required to complete the task with two new target colors. The filler colors were different as well, changing the whole color context (i.e., a new color wheel). The set switch

Experiment 1 results

Fig. 3 Results from Experiment 1. Errors bars represent standard error of the mean. **a** Results from the first half of training in the Repeat group, broken down by trial type and lag. **b** Results from the first half of training in the Set Switch training group, broken down by trial type and lag. **c** Results from the Repeat group at test, broken down by trial type and lag. **d**

Results from the Set Switch group at test, broken down by trial type and lag. **e** Results from the Repeat group comparing the first half of training to test, collapsing across lag. **f** Results from the Set Switch group comparing the first half of training to test, collapsing across lag

hypothesis predicted that set-specific capture costs would be reduced in the Set Switch training group compared to the Repeat training group in the test phase. Meanwhile, the associative learning hypothesis predicted

that set-specific capture costs in the Set Switch training group would return to pretraining levels in the test phase, because the specific learned associations would no longer be present.

Table 2 Experiment 1 results from two ANOVAs, using test phase data

ANOVA data & design		Effects		Statistics			Descriptives		
Training Group(s)	ANOVA factors	Main effects	Interactions	<i>df</i>	<i>F</i>	<i>p</i>	η_p^2	Larger mean (<i>SD</i>)	Smaller mean (<i>SD</i>)
<i>Both</i>	<i>Training group (Set Switch, Repeat); Trial type (STC, DTC); lag (1, 4)</i>		Training Group $\times$ Trial Type						
		STC > DTC		(1, 52)	4.40	.041	0.077		
		lag 4 > 1		(1, 52)	36.04	<.001	0.405	0.808 (0.101)	0.688 (0.127)
		Set Switch > Repeat		(1, 52)	24.19	<.001	0.313	0.797 (0.120)	0.699 (0.102)
<i>Set Switch</i>	<i>Trial type (STC, DTC); lag (1, 4)</i>			(1, 52)	8.34	.006	0.138	0.778 (1.180)	0.688 (1.080)
		STC > DTC	(1, 26)	14.05	<.001	0.369	0.818 (0.104)	0.768 (0.125)	
		lag 4 > 1	(1, 26)	8.63	.007	0.265	0.814 (0.104)	0.772 (0.125)	
<i>Repeat</i>	<i>Trial type (STC, DTC); lag (1, 4)</i>			(1, 26)	25.49	<0.001	0.468	0.769 (0.140)	0.607 (0.195)
		STC > DTC	(1, 26)	16.99	0.007	0.369	0.750 (0.150)	0.626 (0.185)	

Note. The first ANOVA is a between-subjects comparison of test phase results and demonstrates reduced set-specific capture effects in the Set Switch group compared to the Repeat group. The second and third ANOVAs show that set-specific capture is significant in both training groups, even the Set Switch group, in spite of the reduction occurring as a result of training in this group. For effects that compare two means, the higher mean is listed first and the smaller mean is listed second. Standard deviations are in parentheses

Method

Participants

Seventy-two students, ages 18 to 30 years, 38 from Elmhurst College and 34 from Arcadia University, participated in the experiment for course credit or \$10. All reported normal or corrected vision. Participants provided written informed consent before starting the experiment in accordance with the Elmhurst College and Arcadia University Institutional Review Boards.

We used Experiment 1 data to calculate the sample size needed to observe the same training effect in set-specific capture at 80% power. We determined that 52 participants were needed, or 26 per condition. We exceeded this goal in our data collection because we wished to account for the possibility of excluding participants and also because we were testing transfer of training in this experiment and figured that the transfer effects, if any, would be smaller than the training effects.

Stimuli and apparatus

We selected colors from two color wheels, one with high luminance (75 L in Lab color space) and the other with low luminance (35 L in Lab color space). Half of participants trained on the light color wheel and were tested on the dark one; the other half trained on the dark color wheel and were tested on the light one. Targets were separated in color space by one or two distractor colors, which appeared as filler in the central RSVP display (see Fig. 1 for RGB values). The size, speed, and display of the letters were the same as in Experiment 1.

Procedure and design

The procedure was similar to Experiment 1, except for a few changes. First, we reduced the number of total colors in each color wheel from six to five. This change helped preserve target visibility across two very different luminance values. With extreme luminance values, parts of a color wheel will appear desaturated (i.e., blues/purples in the light color wheel, and yellows in the dark color wheel), so reducing the total possible colors in the display helps distinguish among slightly desaturated colors. The second reason we made this change was to minimize target-distractor/filler interference from the training segment of the experiment to the test. In other words, we wanted to ensure that colors in the first part of the experiment were not confusable with any colors (distractors or targets) in the second part of the experiment.

Eliminating one of the colors from the wheel prohibited us from testing the non-target-color (NTC) distractor trial type, as there were no longer distractor colors in the color wheels that were perceptually equidistant from both target colors. This

Table 3 Experiment 2 results from a mixed ANOVA, with the between-subjects factor training group (Repeat, Set Switch) and the within-subjects factors phase (first half of training, second half of training), trial type (STC, DTC), and lag (1, 3)

Effects		Statistics				Descriptives	
Main effects	Interactions	<i>df</i> (n,d)	<i>F</i>	<i>p</i>	η_p^2	Larger mean (<i>SD</i>)	Smaller mean (<i>SD</i>)
	Phase × Training Group × Trial Type	(1, 59)	5.33	.024	0.083		
	Phase × Trial Type × lag	(1, 59)	38.45	<.001	0.395		
	Phase × Training	(1, 59)	5.93	.018	0.091		
	Training Group × lag	(1, 59)	10.47	.002	0.151		
	Trial Type × lag	(1, 59)	13.28	.001	0.184		
	Phase × lag	(1, 59)	31.41	<.001	0.347		
Second half > First half training		(1, 59)	17.44	<.001	0.228	0.749 (0.071)	0.687 (0.109)
STC > DTC		(1, 59)	31.24	<.001	0.344	0.791 (0.125)	0.706 (0.179)
lag 3 > 1		(1, 59)	29.43	<.001	0.333	0.791 (0.156)	0.706 (0.164)

Note. The critical result is a meaningful three-way interaction among phase, training group, and trial type. This interaction reflects that set-specific capture effects are smaller in the Set Switch group compared to the Repeat group in the second part of the training phase. For effects that compare two means, the higher mean is listed first and the smaller mean listed second. Standard deviations are in parentheses

decision was deliberate. Because the focus of this investigation was on whether set-specific capture effects could be reduced through training and because we replicated attentional capture already in Experiment 1, eliminating this trial type allowed us to increase our statistical power in the other trial types.

The practice phase of Experiment 2 was the same as in Experiment 1, except that there were no NTC trials (50 trials in total). Additionally, there was a similar two-part practice phase between the training phase and the test phase to acquaint participants with the new colors. This practice phase included the same number of total trials and trial types as the first practice period from the start of the experiment. Practice trials were not analyzed.

Another change we made was to use lags 1 and 3 instead of lags 1 and 4. In prior experiments, we have found large differences between lag 1 and lag 3 performance. That said, lag 3 performance does not usually represent full recovery from distractors, especially on DTC trials. Switching to lag 3 from lag 4 provided a balance of demonstrating some recovery from distraction while maintaining some capture effects.

During the training phase, participants in the Set Switch training group saw 88 TA trials, 48 STC trials (12 per target color per lag), and 192 DTC trials (48 per target color per lag). The trial distribution numbers for the Repeat training group were the same, except with DTC and STC swapped (more STC trials). At test, all participants experienced 28 TA trials, 32 STC trials, and 32 DTC trials.

Results

We first eliminated 11 participants for poor performance (<50% accuracy) on target alone trials during the training and/or test phase. This left us with 29 participants in the Set Switch group, and 32 participants in the Repeat group.

Training effects: Between groups

As an initial analysis, we performed a mixed ANOVA, with all of the experimental factors: training group (Repeat, Set Switch), training phase (first half, second half), trial type (STC, DTC), and lag (1, 3) in order to examine whether training effects from Experiment 1 replicated. We broke the training phase into two epochs because we did not have a test phase on the same colors as in Experiment 1. Most critically, there was a three-way interaction between training group, phase, and trial type, indicating that training reduced set-specific capture in the Set Switch group but not in the Repeat group $F(1, 59) = 5.33, p = .024, \eta_p^2 = 0.083$. ANOVA details are shown in Table 3. This ANOVA also produced main effects of phase (second half was better than first half), trial type, and lag.

Breaking down this ANOVA further, we performed an ANOVA on just the data from the second half of the training phase, with between-subjects factor training group (Repeat, Set Switch) and within-subjects factors trial type (STC, DTC) and lag (1, 3); see Table 4 for details. Consistent with set-specific capture, there were main effects of trial type and lag, and a modest interaction between the two. Replicating Experiment 1 training effects, there was an interaction between training group and trial type, with a greater set-specific capture effect in the Repeat training group ($M = 0.14, SD = 0.05$) than the Set Switch training group ($M = 0.030, SD = 0.06$), $F(1, 59) = 14.46, p < .001, \eta_p^2 = 0.197$. Figure 4 shows this interaction, while collapsing across lag³ (compare STC and DTC bars in Fig. 4a vs. 4b). In the Repeat training group, the simple effect of trial type (set-specific capture) was significant in the second half of training $F(1, 31) = 54.07$,

³ While analyses including lag are reported, lag is excluded from figures for Experiments 2 and 3 for the sake of clarity. lag results are very similar across experiments and conditions. Including them crowds more informative distinctions in the figures.

Table 4 Experiment 2 results from an ANOVA with the factors training group (Repeat, Set Switch), trial type (STC, DTC), and lag (1, 3), using data from the second half of the training period

Effects		Statistics				Descriptives	
Main effects	Interactions	<i>df</i> (n,d)	<i>F</i>	<i>p</i>	η_p^2	Larger mean (<i>SD</i>)	Smaller mean (<i>SD</i>)
	Trial Type $\times$ lag	(1, 59)	4.77	.033	0.075		
	Training Group $\times$ Trial Type	(1, 59)	14.46	<.001	0.197		
NO training group effect		(1, 59)	2.13	.15			
STC > DTC		(1, 59)	31.24	<.001	0.366	0.791 (0.125)	0.706 (0.179)
lag 3 > 1		(1, 59)	29.43	<.001	0.333	0.791 (0.156)	0.706 (0.164)

Note. The results demonstrate that set-specific capture is smaller in the Set Switch group than the Repeat group after some training has occurred. For effects that compare two means, the higher mean is listed first, and the smaller mean is listed second. Standard deviations are in parentheses

$p < .001$, $\eta_p^2 = 0.636$; the same effect was not significant in the Set Switch group $F(1, 28) = 1.87$, $p = .183$.

Training effects: Within groups

We also looked at training effects within each training group by performing two repeated-measures ANOVAs, one for each training group, with the factors training phase (first half of training, second half of training), trial type (STC, DTC), and lag (1, 3). The details of these ANOVAs and their effects can be seen in Table 5. In both training groups, we found main effects of trial type, replicating set-specific capture, and a main effect of phase, as participants in both groups improved from the first half of training to the second. There was also a main effect of lag in the Repeat training group.

Replicating Experiment 1 findings, there was an interaction between phase and trial type in the Set Switch group (Fig. 4a), with set-specific capture costs reduced in this training group during the second half of training compared to the first half of training, $F(1, 28) = 4.5$, $p = .043$, $\eta_p^2 = 0.138$. Set-specific capture was only significant in the Set Switch group in the first half of training $F(1, 28) = 4.23$, $p = 0.049$, $\eta_p^2 = 0.131$, but not in the second half. In the Repeat training group (Fig. 4b), the interaction between trial type and phase was also significant $F(1, 31) = 9.94$, $p = .004$, $\eta_p^2 = 0.243$, but this interaction represented an *increase* in set-specific capture effects from the first to the second half of training, driven by improved performance on STC trials. In this group, set-specific capture was significant in both phases of training.

These analyses largely replicated the results from Experiment 1, showing that set-specific capture effects are affected by practice.

Test phase effects

In order to compare the associative learning and set switching hypotheses, we compared performance in the second half of the training period with performance in the test phase during

which participants completed the same task in a new color context with new target colors. According to the set switching hypothesis, set-specific capture effects should be equivalent between the end of the training phase and the test phase. According to the associative learning hypothesis, any training effects observed from the first to the second half of the training period should wash away at the time of test.

We completed two repeated-measures ANOVAs on each of the training groups with the factors phase (second half of training,

Fig. 4 Results from Experiment 2. Errors bars represent standard error of the mean. **a** Results from the Set Switch group, presented by phase (first half of training, second half of training, or test) and trial type. **b** Results from the Repeat group, presented by phase (first half of training, second half of training, or test) and trial type

Table 5 Experiment 2 results from ANOVAs comparing training effects across phases of the experiment in each training group

Training group	Effects		Statistics			Descriptives		
	Main effects	Interactions	<i>df</i> (n,d)	<i>F</i>	<i>p</i>	η_p^2	Larger mean (<i>SD</i>)	Smaller mean (<i>SD</i>)
<i>Set Switch</i>								
		Phase $\times$ Trial Type	(1, 28)	4.5	.043	0.138		
	STC > DTC		(1, 28)	7.11	.013	0.197	0.768 (0.118)	0.702 (0.113)
	Second half of training > First half of training		(1, 28)	12.04	.002	0.301	0.784 (0.135)	0.686 (0.103)
<i>Repeat</i>								
		Phase $\times$ Trial Type	(1, 31)	9.94	.004	0.243		
	STC > DTC		(1, 31)	31.00	<.001	0.5	0.754 (0.130)	0.647 (0.162)
	lag 3 > 1		(1, 31)	26.28	<.001	0.459	0.732 (0.140)	0.669 (0.151)
	Second half of training > First half of training		(1, 31)	4.69	.038	0.131	0.713 (0.145)	0.688 (0.146)

Note. In each ANOVA, the factors are phase (first half of training, second half of training), trial type (STC, DTC), and lag (1, 3). The Phase $\times$ Trial Type interaction in the Set Switch group reflects reduced capture in the second half of training. The same interaction in the Repeat group actually reflects *increased* set-specific capture following training. For effects that compare two means, the higher mean is listed first and the smaller mean listed second. Standard deviations are parentheses

test), trial type (STC, DTC), and lag (1, 3). The details of these ANOVAs are shown in Table 6. In both of the training groups, we replicated set-specific capture and recovery from capture, as there were main effects of trial type and lag. Both groups also exhibited a main effect of phase. Critically, there was an interaction between phase and trial type in the Set Switch group, with greater set-specific capture effects observed during test than during the second half of training, $F(1, 28) = 5.71$, $p = .024$, $\eta_p^2 = 0.169$ (Fig. 4a). This result is consistent with the associative learning hypothesis because it suggests that training effects observed in the first half of the experiment were washed away at test. However, it is possible that *some* training effects

transferred to the new context but that they were not as robust as at the end of the training period. In that case, set-specific capture effects should be smaller in the test phase in the Set Switch group than they are in the first half of training. Consistent again with the associative learning hypothesis, we found no significant difference in set-specific capture effects between these two phases of the experiment, $F(1, 28) = 1.09$, $p = .306$.

In the Repeat training group, there was also an interaction between phase and trial type, with greater set-specific capture during the second half of training than during test. This result was driven by increased performance on STC trials during the

Table 6 Experiment 2 results from ANOVAs investigating transfer of training in each training group

Effects			Statistics			Descriptives	
	Main effects	Interactions	<i>df</i> (n,d)	<i>F</i>	<i>p</i>	η_p^2	Larger mean (<i>SD</i>) Smaller mean (<i>SD</i>)
<i>Set Switch</i>							
		Phase $\times$ Trial Type	(1, 28)	5.71	.024	0.169	
		Trial Type $\times$ lag	(1, 28)	15.78	<.001	0.360	
	Second half of training > Test		(1, 28)	9.83	.004	0.260	0.713 (0.156) 0.655 (0.214)
	STC > DTC		(1, 28)	6.34	.018	0.185	0.728 (0.142) 0.640 (0.214)
	lag 3 > 1		(1, 28)	35.02	<.001	0.556	0.744 (0.156) 0.624 (0.196)
<i>Repeat</i>							
		Phase $\times$ Trial Type	(1, 31)	28.88	<.001	0.482	
	Second half of training > Test		(1, 31)	16.29	<.001	0.344	0.713 (0.150) 0.655 (0.162)
	STC > DTC		(1, 31)	27.20	<.001	0.467	0.728 (0.135) 0.640 (0.178)
	lag 3 > 1		(1, 31)	26.79	<.001	0.464	0.744 (0.151) 0.624 (0.173)

Note. In each ANOVA, the factors are phase (second half of training, test), trial type (STC, DTC), and lag (1, 3). Most importantly, set-specific capture effects were larger at test than in the second half of training in the Set Switch group, supporting the associative memory hypothesis. For effects that compare two means, the higher mean is listed first, and the smaller mean listed second. Standard deviations are parentheses

second half of the training period, a practice effect that did not transfer to the new color context. Though the focus of this series of experiments is on training of DTC trials, this result in the Repeat training group also provides ancillary evidence for the associative learning hypothesis, as it demonstrates that STC trial training does not transfer when the color context changes, just as the DTC trial training does not transfer in the Set Switch training group.

Discussion

We replicated the general findings from Experiment 1, showing training effects of set-specific capture. In particular, set-specific capture was reduced in the Set Switch training group compared to the Repeat training group when examining the second half of training trials. Also, within the Set Switch training group, set-specific capture effects were reduced in the second half of training compared to the first half of training, whereas in the Repeat training group the opposite effect was observed.

However, set-specific capture effects returned in the Set Switch training group during the test phase, when the participants were required to search for two new target colors. This result indicates there was no transfer of training to a new color context and provides evidence for the associative learning hypothesis.

While Experiment 2 provides evidence against the set switching hypothesis, it is possible that participants did in fact learn to switch between sets flexibly during training but could only transfer this skill within the *same* color context. Changing both the target colors *and* the context may have eliminated some of the cues necessary to exploit trained flexible set switching. In Experiment 3, we set out to test the set switching hypothesis under less strict conditions, in which transfer of training is most likely to occur.

Experiment 3

In Experiment 3 we examined whether trained set-specific capture improvement transfers within the same color context. To do so, we designed the training phase the same way as in Experiment 1 using the same six-color wheel (see Fig. 1), but with no NTC trials. During the training phase, only five of the six colors appeared—two as target colors and three as fillers. During test, the sixth color was added as an additional target to maintain and search for along with the other two trained targets. Using this method, we could measure performance on “new” DTC trials in which the distractor or the target was the newly learned color, and compare these to “old” DTC trials that were practiced from the training phase, in which both the distractor and target colors were highly familiar.

If participants are able to transfer their training to a new target color as predicted by the set switching hypothesis, then set-specific capture among conditions involving the “old” target

colors should be equivalent to set-specific capture in conditions involving the “new” target color for participants in the Set Switch training group. Suppose, for example, a participant in the Set Switch training group looks for green and lavender targets in the training phase of the experiment, and during test, a new target color (orange) is added to the set of target colors. Consistent with Experiments 1 and 2, the participant should have a reduced performance difference between “old” STC (e.g., green-green) trials and “old” DTC (e.g., green-lavender) trials following training. In other words, set-specific capture should be reduced in the Set Switch training group compared to the Repeat training group. According to the set switching hypothesis, this set-specific capture magnitude difference in the training groups should be observed for the “new” STC (e.g., orange-orange) trials and “new” DTC (e.g., green-orange) trials, which would indicate that participants have trained a general ability to set switch within a similar color context. However, the associative learning hypothesis predicts that training would not transfer to the new target color, because the learned associations are too specific. Therefore, according to this hypothesis, set-specific capture effects involving the new target color should revert back to pretraining levels and be equivalent across training groups.

Method

Participants

One hundred three people, ages 18 to 30 years, participated in the experiment for course credit or \$10. Twenty were students at Purdue University; eight were from the Elmhurst, Illinois, community; 44 were students at Elmhurst College; and 31 were students at Arcadia University. All reported normal or corrected vision. Participants provided written informed consent before starting the experiment in accordance with the each of Elmhurst, Purdue, and Arcadia’s Institutional Review Boards.

To determine the appropriate sample size, we once again used test phase data from Experiment 1. Given that the results from Experiment 2 provided evidence for the associative learning hypothesis, which is a null effect of training, we opted for a sample size that would achieve 90% power for the set-specific capture training effect so that we could ensure sufficient power to reject the null hypothesis. Our estimated sample size based off of the higher power standard and smaller number of trials per condition was 98 participants, or 49 per condition. After eliminating poor performers, we fell just short of this goal, with 47 participants per condition (see [Results section](#)).

Stimuli and apparatus

We used the same color scheme as in Experiment 1. The trained target colors were any two of orange, green, and lavender (counterbalanced across participants). The third target color, which was never presented to participants during the

training phase, was the third of these colors. The size, speed, and display of the letters were the same as in Experiment 1.

Procedure and design

The procedure was similar to both Experiments 1 and 2, except for a few changes. The initial practice and training phase were identical to Experiment 1, except with different trial distributions because there was no NTC trial type in this experiment. The trial distribution during the practice phase was the same as in Experiment 1 but with the NTC trials eliminated, for a total of 46 practice trials. The distribution of trials in the training phase was as follows. In the Set Switch training group, participants saw 88 TA trials, 48 STC trials (12 per target color per lag), and 200 DTC trials (50 per target color per lag). The trial distribution numbers for the Repeat training group were the same except with DTC and STC swapped (more STC than DTC trials).

In the test phase of the experiment, participants were required to look for three target colors, including the two already trained as well as a new target color. Each target color was separated from the other two in color space by a single filler color (see Fig. 1a). The addition of this target color generated several new conditions. We labeled these conditions according to trial type (TA, STC, DTC) as well as the identity of the distractor color (if applicable) and target color: “old” (trained color) or “new.” For example, if the participant was trained on green and lavender and orange was added to the target list during the test phase, then a trial in the test phase with a green distractor and an orange target would be called “DTC-old-new.” See Fig. 5 for an explanation of trial types in Experiment 3.

During the test phase, there were several more trial types than before, with the addition of the new color. Because we did not want to burden the participants with a large number of trials and we did not want any effects from the training period to wear off,

we changed the trial distribution in the test phase to include only trials at lag 1, because at lag 1 the effects of distraction are most powerful (Moore & Weissman, 2010). Thus, these were the conditions and number of trials per condition during the test phase: TA-old (16, eight per color); TA-new (eight), STC-old-old (32; 16 per color); DTC-old-old (32, 16 per color); STC-new-new (16); DTC-new-old (i.e., new target color as the distractor, old target color as the target: 16 trials, eight per color); DTC-old-new (16 trials, eight per color).

Before the start of the test phase, there was a practice phase for participants to learn the new target color and to practice searching for three target colors. As in the start of the experiment, this practice session included two parts. In the first part, a box colored with the new target color was always present above the stimulus so participants would have an easier time remembering this target color. Practice phase timing was the same as in Experiments 1 and 2. There were 12 trials, all target alone, and 10 of them were of the new color. In the second stage of practice, participants viewed the experiment at full speed and received all trial types once each, with five additional target alone trials in the new color, for a total of 20 trials. The colored box was removed during this part of practice.

Results

At the outset, we eliminated nine participants, five from the Set Switch training group and four from the Repeat training group, due to subpar performance, which we defined as less than 50% accuracy on TA trials, TA-old trials, or TA-new trials. This left each group with 47 participants.

Training effects: Between subjects

We first tested whether set-specific capture and training results were replicated in Experiment 3. To do so, we focused the test phase analyses on trials involving the original two searched-for colors (“old” trials). We also limited analyses to lag 1 trials in order to compare training data to test phase data, which only included lag 1 trials. As an initial analysis, we performed a mixed ANOVA with all of the experimental factors: training group (Repeat, Set Switch), phase (first half of training, test), and trial type (STC/STC-old-old, DTC/DTC-old-old). As in Experiment 2, there was a three-way interaction between training group, phase, and trial type, indicating that training reduced set-specific capture in the Set Switch group but not in the Repeat group $F(1, 92) = 4.89, p = .029, \eta_p^2 = 0.050$. ANOVA details are shown in Table 7. This ANOVA also produced main effects of phase, trial type, and training group.

Breaking this result down, we performed the same analysis using just test phase data. ANOVA details are in Table 8. We found a main effect of training group, with higher performance in the Set Switch group ($M = 0.750, SD = 0.176$) than in the Repeat group ($M = 0.669, SD = 0.169$), $F(1, 92) = 7.05, p =$

Fig. 5 Design and trial types of Experiment 3. In the test phase of Experiment 3, participants complete all of the same trial types as before, but are also required to search for a third color. In this example, assume lavender and green are the initial target colors the participants searches for during training. Orange is the third target color added just before test. (Color figure online)

Table 7 Experiment 3 results from a mixed ANOVA, with the between-subjects factor training group (Repeat, Set Switch) and the within-subjects factors phase (first half of training, test) and trial type (STC/STC-old-old, DTC-old-old), using trials with just the old target color

Effects	Statistics				Descriptives		
	Interactions	<i>df</i>	<i>F</i>	<i>p</i>	η_p^2	Larger mean (<i>SD</i>)	Smaller mean (<i>SD</i>)
Main effects							
	Phase $\times$ Trial Type $\times$ Training Group	(1, 92)	4.89	.029	0.050		
	Trial Type $\times$ Training Group	(1, 92)	5.76	.018	0.059		
Test > First half training		(1, 92)	12.53	.001	0.120	0.705 (0.116)	0.650 (0.095)
STC > DTC		(1, 92)	64.63	<.001	0.413	0.772 (0.102)	0.583 (0.136)
Set Switch > Repeat		(1, 92)	9.52	.003	0.094	0.720 (0.136)	0.636 (0.136)

Note. The three-way interaction among phase, training group, and trial type reflects that set-specific capture effects were smaller in the Set Switch group compared to the Repeat group following training, replicating training effects from Experiments 1 and 2. For effects that compare two means, the higher mean is listed first, and the smaller mean listed second. Standard deviations are parentheses

.009, $\eta_p^2 = 0.071$. We will return to this result in the general discussion. Most importantly, we found an interaction between training group and trial type, indicating reduced set-specific capture in the Set Switch training group but not the Repeat training group, a result replicating Experiments 1 and 2, $F(1, 92) = 6.18$, $p = 0.015$, $\eta_p^2 = 0.063$ (compare the STC and DTC bars in Fig. 6a vs. 6c, for the test phase). Set-specific capture was still significant during the test phase in both training groups: Repeat: $t(46) = 4.17$, $p < .001$; Set Switch $t(46) = 2.27$, $p = .028$. Together, these results confirm that training can reduce set-specific capture costs on the specific stimuli that are practiced during the training phase.

Training effects: Within subject

Next, we performed two repeated-measures ANOVAs, one for each training group, with the factors experiment phase (first half of training, test) and trial type (STC/STC-old-old, DTC/DTC-old-old). ANOVA details can be found in Table 9.

In both groups there was a main effect of trial type, replicating set-specific capture. In the Set Switch training group, there was an interaction between phase and trial type, demonstrating that set-specific capture was reduced following training on DTC trial types, among the practiced colors, $F(1, 46) = 6.47$, $p = .014$, $\eta_p^2 = 0.123$ (compare STC and DTC bars in Fig. 6c for the two training phases). A post hoc paired-samples *t* test confirmed that in this training group, performance on DTC-old-old trials during

test ($M = 0.723$, $SD = 0.305$) was significantly better than performance on DTC trials during the first half of training ($M = 0.583$, $SD = 0.188$), $t(46) = 2.81$, $p = .007$.

Of note, there was no interaction between phase and trial type in the Repeat group ($F < 1$), indicating no change in the magnitude of set-specific capture from training to test (Fig. 6a). Thus, the primary findings from Experiment 1 and 2 were replicated.

Test phase effects

Before examining the critical trial types with the new target color, we compared the TA-old and TA-new trials to ensure that participants had learned to search for the new color and were doing so as effectively as they searched for the old colors. If participants had not learned to search for the new color, a reduction in performance in the Set Switch training group from DTC-old-old to DTC-old-new trials could reflect *either* a lack of transfer of training (in support of the associative learning hypothesis) *or* reduced target salience, because the participant has only recently learned to search for the new target. Alleviating this concern, TA-new and TA-old performance was equivalent, $t(93) = 0.583$, $p = .561$ (TA-old $M = 0.80$, $SD = 0.156$; TA-new $M = 0.789$, $SD = 0.137$), demonstrating that participants were able to learn the new target color rapidly.

Table 8 Experiment 3 results from an ANOVA using test phase data, with the between-subjects factor training group (Repeat, Set Switch), and within-subjects factor trial type (STC-old-old, DTC-old-old)

Effects	Statistics				Descriptives		
	Interactions	<i>df</i>	<i>F</i>	<i>p</i>	η_p^2	Larger mean (<i>SD</i>)	Smaller mean (<i>SD</i>)
Main effects							
	Training Group $\times$ Trial Type	(1, 92)	6.25	.014	0.064		
Set Switch > Repeat		(1, 92)	7.28	.008	0.073	0.751 (0.163)	0.658 (0.163)
STC > DTC		(1, 92)	14.29	<.001	0.134	0.787 (0.156)	0.622 (0.218)

Note. The ANOVA shows greater set-specific capture in the Repeat group than the Set Switch group, indicating a replication of Experiments 1 and 2 training effects. For effects that compare two means, the higher mean is listed first, and the smaller mean listed second. Standard deviations are parentheses

Fig. 6 Results from Experiment 3. Errors bars represent standard error of the mean. **a** Repeat group results, comparing the first half of training (lag-1 trials only) to equivalent trials (“old” colors) at test. **b** Repeat group results from test trials involving the “new” target color. **c** Set

Switch group results, comparing the first half of training (lag-1 trials only) to equivalent trials (“old” colors) at test. **d** Set Switch group results from test trials involving the “new” target color

Test phase effects: Between subjects

First, we compared trials with the new target color across both training groups by conducting an ANOVA with the factors training group (Repeat, Set Switch) and condition (STC-new-new, DTC-old-new). If any transfer has occurred (in support of the set switching hypothesis), set-specific capture

effects should be larger in the Repeat training group than in the Set Switch training group for trial types with the new target color. Consistent with the associative learning hypothesis, set-specific capture was roughly equivalent across both training groups, $F(1, 92) = 1.06, p = .307$. This can be seen comparing Fig. 6b to d: the difference between STC trials and both types of DTC trials is similar across both training groups.

Table 9 Experiment 3 results from two ANOVAs investigating the effects of training, with the factor phase (first half of training, test) and trial type (Repeat, Set Switch)

Effects		Statistics				Descriptives		
Training group	Main effects	Interactions	<i>df</i>	<i>F</i>	<i>p</i>	η_p^2	Larger mean (<i>SD</i>)	Smaller mean (<i>SD</i>)
<i>Set Switch</i>								
		Phase × Trial Type	(1, 46)	6.47	.014	0.123		
	STC > DTC		(1, 46)	53.47	<.001	0.551	0.786 (0.149)	0.653 (0.185)
<i>Repeat</i>								
		NO Phase × Trial Type	(1, 46)	< 1				
	STC > DTC		(1, 46)	68.28	<.001	0.597	0.758 (0.149)	0.513 (0.203)
	NO phase (Test > First half of training)		(1, 46)		.057		0.658 (0.170)	0.613 (0.143)

Note. These analyses use old/original target colors in the test phase versus first half of training. The first ANOVA shows that set-specific capture is reduced in the Set Switch group following training. The second ANOVA shows no change in set-specific capture following training in the Repeat group. For effects that compare two means, the higher mean is listed first, and the smaller mean listed second. Standard deviations are parentheses

Though this ANOVA suggests no difference in set-specific capture across the two groups on trials with the new color, providing support for the associative learning hypothesis, it is important to note that comparing just the DTC trial types across groups paints a different picture. For both the DTC-old-new trial type and the DTC-new-old trial type, performance was higher among Set Switch participants than among Repeat participants: DTC-old-new, $t(92) = 2.60$, $p = .011$ (Set Switch $M = 0.600$, $SD = 0.047$; Repeat $M = 0.415$, $SD = 0.052$). DTC-new-old, $t(92) = 2.64$, $p = .010$ (Set Switch $M = 0.696$, $SD = 0.047$; Repeat $M = 0.511$, $SD = 0.047$). The reason these simple effects are significant whereas the interaction in the ANOVA is not is because STC-new-new performance was *also* higher in the Set Switch group than in the Repeat group (compare STC trials in Fig. 6b and d); this result was marginally significant, $t(92) = 1.99$, $p = .049$ (Set Switch $M = 0.851$, $SD = 0.037$; Repeat $M = 0.761$, $SD = 0.026$). We will return to this result and its implications in the General Discussion section.

Test phase effects: Within subjects

We next examined how performance changed within groups when the new target color was introduced. According to the set switching hypothesis, the decreased set-specific capture result observed in the Set Switch training group for old colors should transfer to the new target color. We conducted a repeated-measures ANOVA on the Set Switch training group participants with the factors trial type (STC, DTC) and target color (old, new) using just test phase data. Thus, the trial types tested were STC-old-old, STC-new-new, DTC-old-old and DTC-old-new. Consistent with the associative learning hypothesis, the magnitude of capture was significantly greater when the target was the new target color (STC-new-new–DTC-old-new) than when just the old target colors were used (STC-old-old–DTC-old-old), $F(1, 46) = 7.57$, $p = .008$, $\eta_p^2 = 0.141$. Performing the same ANOVA on the Repeat training group, there was no difference in STC-DTC trial performance when the target was the new target color versus the old target color ($F < 1$). That is, set-specific capture effects were robust for both old and new target colors.

Finally, we compared set-specific capture effects in the Set Switch training group using (a) the first half of training (“old” colors) (STC and DTC bars in Fig. 6c, first half training) and (b) the test phase with the new color as the target (STC and DTC-old-new bars in Fig. 6d). We reasoned that if the training does not transfer to the new target color (consistent with the associative learning hypothesis), set-specific capture effects for this new target color should be equivalent to set-specific capture magnitude before much training had occurred for the old target colors. This result bore out as expected: a repeated-measures ANOVA with the factors phase (first half of

training, test) and condition (STC, DTC) in the Set Switch training group yielded no significant interaction, $F < 1$, suggesting that set-specific capture for the new target color was equivalent to set-specific capture effects prior to training on the old colors.

Discussion

We replicated findings from Experiments 1 and 2 of capture, set-specific capture, and reduced set-specific capture effects for participants in the Set Switch training group. Consistent with the findings from Experiment 2, we found that these practice effects did not transfer to a new target color, even when the rest of the color context remained consistent. This result provided further evidence against the set switch hypothesis in favor of the associative learning hypothesis. However, participants in the Set Switch group performed better overall in the test phase than did those in the Repeat group. This result implies a more extensive training outcome than that predicted by the associative learning hypothesis.

General discussion

Set-specific capture is a performance cost found when attempting to search for more than one item at a time under conditions of distraction due to a focus of attention that can temporarily hold only one attentional set (Moore & Weissman, 2010, 2011, 2014). We investigated whether and how practice can overcome set-specific capture. Across three experiments, we observed that set switching practice mitigates set-specific capture. However, this benefit in performance did not extended beyond the particular requirements of the trained task, not to a new set of colors (Experiment 2) or to a new color within the same color context (Experiment 3). We rejected the “set switching” hypothesis, which posited that participants had learned to switch attention more rapidly and flexibly through training. Instead, we adopted the “associative learning” hypothesis, which posited that participants are learning to associate the two target colors in a specific and low-level fashion.

One feature of the results from the present study is that the association between the colored distractor and the target is learned even though the stimuli are appearing 116 ms apart. Typically when a distractor appears just 116 ms prior to a target, the distractor occupies attention and prevents participants from even detecting that a target was presented. However, even in this short time frame, participants were able to make an association between the distractor color and target color in order to come to expect a particular target color to follow a distractor color, and prepare attention accordingly (and rapidly). It might be the case that in the present study, as well as in other RSVP tasks, targets that are missed are nevertheless processed at a preconscious level (see also Le

Pelley et al., 2013, for an example of associative learning between two stimuli presented in rapid succession).

Previous studies have investigated how attentional sets can be learned and employed through practice, and these studies provide insight into the interpretation of our results, even though they were limited to instances in which participants maintained a single search goal within a task. In these experiments, participants were learning to suppress distractors (Vatterott & Vecera, 2012) or employ a particular strategy or attentional set (Irons & Leber, 2016; Leber et al., 2009). Our findings align more closely with those that suggest stimulus-specific learning with practice (Vatterott & Vecera, 2012) than those supporting abstract learning (Leber et al., 2009).

The adjustment in attentional control settings that takes place through consistent associations, as in the present study and in similar ones, may relate to other attentional control micro-adjustments that occur during visual search tasks based on priming from the previous trial. In studies finding intertrial priming during visual search, participants are influenced by an irrelevant feature of a distractor or target on the previous trial in their search for a target on the current trial (Folk & Remington, 2008; Meeter & Olivers, 2007). The distractor preview effect is similar—a feature is more easily ignored when it occurs on a distractor on the previous trial (Levinthal & Lleras, 2008). Some have suggested that intertrial effects can account for a large component of top-down attention effects (such as in contingent attentional capture; Lamy & Kristjánsson, 2013). A difference between these investigations and the present study is that intertrial priming and the distractor preview effect involve adjustments to the attentional control settings that are occurring over a short time frame—trial by trial—as opposed to learning that is developed across a long series of trials.

Another way to consider the learning that occurred in each experiment before the context/targets were changed is to describe the results as a training of “visual expectation” rather than training of visual attention (Summerfield & Egnér, 2009). Other examples of visual expectation in the literature include findings in which object recognition is faster and more accurate when the object appears in an appropriate contextual scene than when it appears alone or in an unexpected context (Hollingworth & Henderson, 1998); or when the detection of a simple object or feature is facilitated by irrelevant stimuli that guide visual attention to that feature (Auckland, Cave, & Donnelly, 2007). These examples rely on learning that has occurred over years of the observers’ visual experience, but in this case we have found it is possible to modulate visual expectation through the course of a relatively brief experimental session. Similar effects have been found in studies on visual statistical learning (Fiser & Aslin, 2002; Turk-Browne, Isola, Scholl, & Treat, 2008).

A limitation of the present study, as well as other training studies finding null results, is that one can always wonder

whether the training was sufficient to have an effect on behavior. The training period of about 200 critical trials was sufficient to observe a consistent effect on performance within the identical context of the study across all three experiments (i.e., without any colors changing). However, it is possible that transferring to a new color or context requires more practice trials in order to develop a general set switching skill. A related possibility is that gains in set switching could have worn off during the second practice session in Experiments 2 and 3, in which new target colors were introduced. Analyzing the practice trials did not provide conclusive information on this issue, as power was quite low in these trials, and performance poor. We cannot speak to whether a longer training regimen (or shorter practice) has an impact on set-specific capture.

One peculiar finding from both Experiments 1 and 3 was that participants in the Set Switch training group had significantly better overall accuracy than participants in the Repeat training group. In Experiment 3, this also meant that participants in the Set Switch group performed better on DTC-old-new trial type (set-specific capture condition with the new color as a target color) than did participants in the Repeat group, a finding more in line with the set switching hypothesis than the associative learning hypothesis. Notably, participants in the Set Switch group *also* performed marginally better than participants in the Repeat group on STC-new trial type. In Experiment 1 target alone and even STC performance was numerically higher in the Set Switch than in the Repeat training group. These results agree in part with training studies on task switching. As stated previously, gains in mixing costs following training may transfer, whereas gains in switch costs do not (Minear & Shah, 2008). The Set Switch training group effects that may have transferred were more akin to “mixing costs,” as they reflected overall gains in multitasking performance. Meanwhile, the effects that did not transfer—set-specific capture—were more akin to “switch costs.” Though none of the experiments provided evidence that Set Switch training led to more flexible set switching, further research may investigate whether Set Switch training could lead to other visual attention gains, such as distractor suppression or maintaining multiple search goals in the absence of distraction.

The findings from the present study add to a growing literature showing that there are significant costs to multitasking. Set-specific capture represents a largely immutable and pervasive multitasking cost in visual search, similar to the costs seen in other forms of multitasking. On the other hand, low-level associative learning has a substantial impact on set-specific capture in the context of a visual search task for color. Future visual attention studies using color should be designed with this knowledge in mind; participants are constantly learning associations across stimuli within a trial in addition to detecting patterns from one trial to the next and throughout the experiment.

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