Flexible transfer of item-specific cognitive control: From Stroop to visual search

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Trial-level data and analysis scripts for all experiments are available on the Open Science Framework repository at https://osf.io/mc62z. None of the experiments was pre-registered.

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Abstract

When repeatedly encountering the same challenge, we learn environmental regularities that predict its reoccurrence and use them to prepare for future encounters. For example, the red color of a stop sign may automatically trigger caution. Past research shows such associative learning flexibly regulates cognitive control and generalizes to similar tasks. A key open question is whether learned control transfers to novel challenges with distinct control demands, and whether such transfer reflects perceptual, feature-based priming or higher-level, goal-based control adaptation. The present study addressed these questions by examining whether cognitive control learned in a Stroop task, that requires information dimension selection, transfers to spatial location selection in visual search. Participants learned item-specific control in a Stroop color-naming task where *mostly incongruent* colors signaled higher control demands than *mostly congruent* colors. In a subsequent visual search task, those colors no longer signaled control demands and instead appeared as task-irrelevant distractors while participants searched for a target. This reversal in the roles of the colors enabled a resolution of whether learned control engages feature-based priming or goal-based adaptation. The results support the latter, showing that learned control successfully transferred and adapted to the new goal, such that distractors in the colors previously associated with heightened control demands were more effectively ignored than those associated with relaxed control demands. This cross-task transfer from non-spatial to spatial attentional selection demonstrates a remarkable flexibility of item-specific cognitive control, whereby goal-based adaptation supports generalization across dissimilar contexts, adjustment to reversed stimulus roles, and resolution of novel challenges.

Key words: cognitive control, learning, transfer, spatial attention, visual search

Public Significance Statement

This study shows that people can learn to use environmental cues to regulate attention and then apply that learning to new situations with different demands. Rather than mechanically repeating past

patterns of attention, learned control flexibly adapts to current goals, allowing people to effectively respond to novel challenges. These findings reveal a powerful mechanism by which past experience can shape adaptive behavior across diverse real-world contexts.

Cross-Task Transfer Reveals Key Mechanisms of Item-Specific Cognitive Control

With our everyday lives comprised of many repeated routines, we tend to learn the regularities and adjust our behaviors accordingly for anticipated encounters with the same events in the future. For example, when driving through a school zone, you may choose to drive more cautiously, reflecting a global adjustment. Alternatively, you may drive more cautiously only when you spot a child near the roadside, reflecting an adjustment tied to a specific cue.

The ability to recruit a heightened or relaxed attentional state based on the demands of the current situation is referred to as cognitive control (Botvinick et al., 2001; Braem et al., 2019; Gratton et al., 1992; Miller & Cohen, 2001). In classical cognitive control paradigms, these demands are often manipulated through the statistical regularities of conflict. For example, in a color-naming Stroop task, conflict is manipulated by varying the proportion of trials in which the relevant dimension (color) and the irrelevant dimension (word) are congruent (i.e., *proportion congruency*). When the to-be-named colors seldomly match their paired color words, participants tend to engage a control setting conducive to the situation—actively filtering the dominant but irrelevant word-reading process while facilitating the nondominant but relevant color-naming process. On the other hand, when the colors and words are often congruent, people devote less effort to filtering the word (for a review, see Bugg & Crump, 2012). Early studies demonstrated that cognitive control can be adjusted globally in response to the general statistical regularities of a context, such as when one list (i.e., block) of Stroop trials was mostly incongruent and another was mostly congruent (*list-wide proportion congruency*; Botvinick et al., 2001; Bugg, 2014; Bugg et al., 2008; Bugg & Chanani, 2011; Lindsay & Jacoby, 1994; Logan & Zbrodoff, 1979; Suh et al., 2022). More recent studies have additionally shown that cognitive control is not only sensitive to the overall probability of conflict but can also be adjusted on a trial-by-trial basis according to the proportion congruency of individual stimuli (*item-specific proportion congruency, ISPC*; Bugg et al., 2011; Bugg & Crump, 2012; Bugg & Hutchison, 2013; Jacoby et al., 2003). This ISPC effect requires frequent and rapid adjustment of control after stimulus onset, rather than a slow, deliberate process, thus revealing the remarkable flexibility of cognitive control.

Cognitive Control Can Apply to Individual Items

As illustrated by the school zone example, research suggests that not only do people learn the overall attentional demands of a task, but they also learn the demands associated with specific elements of a task, such as stimuli and contexts, resulting in more flexible control (Abrahamse et al., 2016; Braem & Egner, 2018; Bugg & Egner, 2022; Chiu & Egner, 2019; Crump & Milliken, 2009; Egner, 2014). A prominent approach to studying this item-based, flexible control is through an ISPC manipulation, where stimulus features (e.g., colors in a Stroop task), known as items, are associated with different probabilities of being congruent (Bugg et al., 2011; Bugg & Hutchison, 2013; Jacoby et al., 2003; Spinelli et al., 2022). One set of colors is paired with mostly congruent words (the *MC colors*; e.g., the color red frequently presented with the congruent word RED) and another set of colors is paired with mostly incongruent words (the *MI colors*; e.g., the color green frequently presented with the incongruent words RED, BLUE, and YELLOW). Critically, the two sets are randomly intermixed to create an overall 50% probability of conflict (that is, considering all trials, one-half of them are congruent and one-half of them are incongruent). The ISPC effect is the reduction in the *congruency effect* (i.e., the impairment in performance on incongruent trials compared to congruent trials; i.e., Stroop effect) on trials with an MI color compared to trials with an MC color (for ISPC effects with color as the stimulus feature, see e.g., Jacoby et al., 2003; Bugg & Hutchison, 2013; Hutchison et al., 2016; for ISPC effects with stimulus features other than color, see e.g., Bugg et al., 2011; Bugg & Dey, 2018; Chiu et al., 2017; Ileri-Tayar et al., 2025; Suh & Bugg, 2021). This suggests that the association between a color and the probability of conflict can be individually learned, facilitating flexible and rapid changes in control when encountering different colors on different trials (i.e., item-specific control).

Item-specific control can be explained as the retrieval of past experiences of conflict, including importantly the control setting engaged during those experiences, upon re-encountering the color cues that were specifically associated with that experience (Bugg & Crump, 2012; Crump & Milliken, 2009; also see other alternative accounts: *contingency learning account*, Schmidt & Besner, 2008; *response/priming retrieval account*, Cochrane & Pratt, 2021; Gallego et al., 2025). MC colors were mostly experienced

with no conflict and consequently trigger retrieval/execution of a more relaxed control setting when re-encountered on a new trial; conversely, MI colors were mostly experienced with conflict and consequently trigger retrieval/execution of a more heightened control setting. While the ISPC effect demonstrates trial-by-trial flexibility in control, a fundamental question is how flexible the retrieval and execution of the learned control settings is across stimuli or contexts. If item-specific control can only be triggered by stimuli and contexts closely resembling those of the initial learning experience, the potential benefits of item-specific control would be limited by its poor generalizability.

Transfer of Item-Specific Control

Only a few studies have investigated transfer of item-specific control. Two studies demonstrated that the control settings acquired during ISPC training (i.e., learning phase) generalize to novel stimuli *within* the same Stroop task[1] (Bugg & Hutchison, 2013; Ileri-Tayar et al., 2022). Participants were faster to name the color on incongruent trials when a novel word was paired with an MI color than an MC color, consistent with the view that the MI color triggered retrieval/execution of a more heightened control setting. Ileri-Tayar et al. (2022) extended this finding by demonstrating that item-specific control also transfers *across* different cognitive control tasks. Participants acquired item-specific control settings in a Stroop task, and then the transfer effect was tested in a modified flanker task. There, the commonly used arrows in the flanker task were replaced with colored circles and critically all colors were 50% congruent. Participants named the color of the middle circle while ignoring the flanking circles that could be in the same or a different color as the middle circle. The congruency effect in the flanker task was reduced for colors that were previously MI in the Stroop task compared to colors that were previously MC, a pattern that was later replicated in two experiments in which participants trained on flanker and then showed transfer in Stroop (Ileri-Tayar et al., 2024). Going one step farther, another experiment showed that item-

[1] Other studies examined category-level transfer of item-specific control, in which control learned for a semantic category (e.g., birds vs. dogs) generalizes to previously unseen exemplars from that category (Bugg et al., 2011; Bugg & Dey, 2018; Cochrane & Pratt, 2022; Ileri-Tayar et al., 2025). Unlike the transfer reviewed here, category-level transfer is a within-task form of transfer that involves generalization based on shared category membership or broad feature similarity rather than the same control-associated stimulus feature (i.e., color).

specific control learned during a color-word Stroop task transferred to a produce-naming task, in which produce pictures appeared in previously MC or MI colors (e.g., a green pepper in the same green color as in the Stroop training) and participants had to name the object (e.g., say “pepper”; Ileri-Tayar et al., 2024). These findings demonstrate that item-specific control can survive a change of task contexts and is triggered not only when the control-associated colors remain relevant across tasks and the response set is the same (e.g., four colors) but additionally when the colors are no longer the relevant dimension and the response set changes (e.g., four colors vs. four produce names). Further showcasing the flexibility of item-specific control, the ISPC effect was also shown to transfer across response modalities: Colvett et al. (2025) demonstrated the persistence of the ISPC effect when the response modality (manual vs. vocal responses) differed between the training phase and transfer phase in a picture-word Stroop task.

Although the studies just described demonstrate transfer of the ISPC effect across different cognitive control tasks and response formats, the substantial similarities between the two tasks in each study leave open several questions. First, a primary question is whether such transfer would extend more generally across distinctly different tasks. In Ileri-Tayar et al. (2022; 2024), the modified flanker task required a color-naming response as did the Stroop task, which might have facilitated a habitual continuation of the learned control settings. In Ileri-Tayar et al. (2024), although the task changed from naming colors to naming objects (produce) in the transfer phase of one experiment, the color of the object likely played an important role in object identification, especially because the selected objects were strongly associated with canonical colors (e.g., a green pepper or an orange pumpkin). Second, more importantly, although the to-be-filtered stimuli differed between the learning and transfer phases in those studies (e.g., word meaning vs. flanker colors), the underlying conflict remained fundamentally the same: competition between relevant and irrelevant information dimensions. Consequently, the learned control could reflect an abstract mechanism that broadly downweights irrelevant dimensions during response selection (Ileri-Tayar et al., 2022; 2024), but this mechanism may be specific to information-dimension selection. Thus, although previous studies demonstrated transfer of the ISPC effect, they did so across relatively minor variations of the same type of conflict. They did not test whether item-specific control

generalizes to qualitatively different forms of conflict resolution. Such transfer, if it occurred, might instead reflect a generally heightened state of attentional readiness (elicited by the MI colors) that can flexibly improve performance across diverse tasks. For example, past experiences of braking at red stop signs and red traffic lights may transfer to boost scrutiny toward a question marked in red on an exam sheet. The study of cross-task transfer of the ISPC effect therefore has implications for not only the generalizability of learned control, but also the flexibility with which distinct cognitive mechanisms can be recruited. Thus, one objective of the present study was to examine whether item-specific control generalizes to qualitatively different control demands.

A second question raised by past findings of transfer of item-specific control is whether the results reflect adaptation to the new task at a cognitive level, which we refer to here as *goal-based control adaptation*, because the effects can alternatively arise from perceptual priming of previously control-associated colors, which we refer to here as *feature-based priming*. For example, a *dimensional weighting account* has been used to explain item-specific control in the color-word Stroop task (Hutchison et al., 2016; Ileri-Tayar et al., 2024; see Algom et al., 1996; Melara & Algom, 2003), whereby the relative weights assigned to the relevant color dimension and the irrelevant word dimension are adjusted according to the control demands associated with each color. Because MI colors are more difficult to name than MC colors, the color dimension becomes more strongly weighted relative to the word dimension for MI than for MC colors. This account therefore raises the possibility that learned control only selectively upweights the color dimension, rather than retrieving a broader state of attentional readiness that operates less selectively (which we refer to as goal-based control adaptation).

Importantly, the transfer phase tasks used in the earlier studies do not permit distinguishing between these alternatives, because color always remained a task-relevant dimension, either serving as the target itself or facilitating target identification. In particular, transfer to the color flanker task required the same color-naming response as the Stroop task (Ileri-Tayar et al., 2022), meaning that improved performance for MI colors could be explained by either enhanced perceptual processing of the color dimension or goal-based control adaptation. Likewise, in the produce-naming task, enhanced performance

for the MI-colored objects (Ileri-Tayar et al., 2024) could also be explained by perceptual priming because color is an integral feature of the objects and likely facilitates their identification. Thus, existing studies cannot distinguish whether cross-task transfer reflects goal-based control adaptation or feature-based priming. Accordingly, a second goal of the present study was to dissociate these possibilities. To do so, the control-associated colors that were task-relevant in a training phase were presented as task-irrelevant distractors in a transfer phase, where they no longer signaled control demands. This reversal in the functional role of the colors yields opposing predictions for the two accounts: Feature-based priming of to-be-ignored color distractors should impair performance, whereas goal-based control adaptation to the new distractor role of the colors should facilitate ignoring them and thus benefit performance.

The Present Study

The present study examined whether item-specific control can generalize to resolve novel conflicts, with an overarching aim of learning more about the locus of the mechanisms underlying such control. To address these questions, we employed transfer tasks that differed in control demands from the training task *and* reversed the task role of the control-associated colors. Specifically, the control demand of a Stroop task involves attentional selection between different dimensions of information (color vs. word meaning), engaging attentional control to downweight the irrelevant dimension and prioritize the relevant one. This form of control involves selective processing across simultaneously presented information dimensions and resembles everyday situations such as maintaining focus on reading a book in a noisy coffee shop. Meanwhile, other real-world tasks require selectively attending to relevant spatial locations and avoiding irrelevant ones, such as looking for a highway exit sign while ignoring an eye-catching billboard. Although both situations require attentional control, they differ in whether selection operates across information dimensions or spatial locations[2]. The present study tested whether item

[2] The transfer of the ISPC effect from Stroop to flanker tasks demonstrated by Ileri-Tayar et al. (2022, 2024) also involved spatial attentional filtering to some extent. However, the present study differs critically from these prior studies in two aspects. First, the nature of spatial selection was fundamentally different. In the flanker task, the target always appeared at fixation and distractors at predictable flanking locations, allowing spatial filtering to be location-specific and established anticipatorily. The peripheral flankers were also no more physically salient than the target, limiting their competition for spatial attention. In the present study, spatial uncertainty instead

specific control generalizes across these distinct attentional demands. Following an ISPC color-word Stroop training, we examined transfer in visual search tasks, where the previously MC or MI colors appeared as salient distractors while participants searched for a target item. Critically, the search target was defined by shape, making color a task-irrelevant feature in the transfer phase that neither signaled the control demands of the task nor contributed to target identification. Instead, colored items served only as salient distractors whose attentional capture would hinder search performance. Thus, unlike in the Stroop task, the goal was to avoid selecting the irrelevant color distractors and instead to locate the target, allowing us to test whether learned control would transfer to spatial attentional selection and adapt to the reversed functional role of the colors.

In three experiments, we progressively deepened the investigation on the transfer of item-specific control from a non-spatial to a spatial attention task. All experiments presented the previously control-associated colors as salient, irrelevant distractors during visual search tasks in the transfer phase. Specifically, Experiment 1 used an additional singleton paradigm (Pashler, 1988; Theeuwes, 1992) that maximizes attentional capture by the distractor, and evaluated the odds of distraction by different control-associated colors. Experiment 2 used a specific-target search task (Bacon & Egeth, 1994; Gaspelin et al., 2015; Leber & Egeth, 2006) that permits ignoring of the distractors, and evaluated to what extent different control-associated colors can be filtered. Experiment 3 used a cued visual search (Meyer et al., 2020; Posner, 1980), in which the control-associated colors served as uninformative cues of the target location. By examining the cue validity effect, we were able to track whether spatial attention was actually allocated to the location of the control-associated colors.

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required dynamic selection among competing locations in our transfer tasks, while the salient distractor provided a strong source of competition for attention. Second, the nature of the conflict differed. In the flanker task, conflict primarily arose from irrelevant color information interfering with response selection, functionally resembling the competition between relevant and irrelevant information in Stroop. In the transfer tasks in the present study, the distractor did not directly compete with the target at response selection but instead interfered with the allocation of spatial attention. Thus, the present study tested transfer to a qualitatively distinct form of attentional control, requiring dynamic spatial selection and resistance to attentional capture.

If learned item-specific control successfully transfers from a non-spatial to a spatial attention task, differences in performance should emerge when MC- and MI-colored distractors are present. Critically, the predicted direction of this effect differs depending on the underlying mechanism: On the one hand, the ISPC effect during Stroop training may reflect feature-based priming, whereby the color dimension is more strongly weighted for MI than MC colors. Under this explanation, during visual search, continued priming of the MI colors should cause the MI distractors to capture more attention and produce greater interference than MC distractors. On the other hand, the ISPC effect may reflect stronger control associated with the MI colors than the MC colors that can adapt to novel task demands in a goal-based manner. Under this explanation, encountering an MI-colored distractor should retrieve general attentional readiness, facilitating the filtering of salient distractors and resulting in smaller performance impairments than those produced by MC distractors. Therefore, the present study provides a critical test of whether cross-task transfer of item-specific control is driven by persistent perceptual biases or by a flexible control mechanism that adapts to novel task demands. Any evidence for goal-based control adaptation would indicate that learned control is represented at a level that transcends the original stimulus roles, allowing it to overcome reversed target–distractor functions and resolve novel challenges.

Experiment 1

Experiment 1 examined whether item-specific control learned in a Stroop task can transfer to the control of spatial attention in a visual search task. In an initial learning phase, participants completed an ISPC color-word Stroop task, in which two of the four stimulus colors were MC items whereas the other two colors were MI items. In a subsequent transfer phase, participants completed an additional singleton task (Theeuwes, 1992), searching for a unique shape target among an array of homogeneous non-target shapes. All shapes were gray, except on some trials, one of the non-target shapes was uniquely colored in either an MC or MI color from the earlier Stroop training. Such shapes are referred to as color singleton distractors. Previous studies indicate that when searching for a unique shape, participants tend to conveniently adopt a *singleton-detection mode*, making them susceptible to attentional capture by a color singleton distractor, even though the uniqueness in the color dimension is irrelevant to the task goal

(Bacon & Egeth, 1994; Pashler, 1988). If control settings learned in a non-spatial Stroop task transfer to spatial attentional control then we would expect unique influences of MC and MI color distractors. Critically, the predicted direction of this effect depends on the mechanism underlying the ISPC effect: If the effect reflects goal-based control adaptation, the learned control should be flexibly adjusted to the demands of visual search, such that the MI-color distractor, which previously signaled heightened control demands, produces a smaller performance cost than the MC-color distractor, which previously signaled more relaxed control demands. In contrast, if the ISPC effect reflects feature-based priming, strongly weighted MI colors should continue to receive preferential processing, causing MI-colored distractors to capture more attention and produce greater interference than MC-colored distractors.

Method

Participants

Twenty-four undergraduate students were recruited to participate in the experiment for course credit. Power analyses were conducted separately for the training and the transfer phases in G*Power (Erdfelder et al., 1996). The training phase effect sizes referenced in the power computation were the average effect size (mean $\eta_p^2 = 0.43$) across three color-word Stroop experiments in Ileri-Tayar et al. (2022; Experiment 1: $\eta_p^2 = 0.62$; Experiment 2: $\eta_p^2 = 0.26$, Experiment 3: $\eta_p^2 = 0.41$) that used a similar ISPC design to the present study. A sample of N = 13 was sufficient to detect the ISPC effect during training with a power of .80. For the transfer phase, we referenced the average effect size of transfer-phase ISPC effects (mean $\eta_p^2 = 0.08$) across four experiments from two studies that examined cross-task transfer of the effect (Experiment 3 in Ileri-Tayar et al., 2022: $\eta_p^2 = 0.05$; Experiment 1: $\eta_p^2 = 0.17$, Experiment 2: $\eta_p^2 = 0.09$, and Experiment 3: $\eta_p^2 < 0.01$ in Ileri-Tayar et al., 2024). A sample size of N = 25 was sufficient to detect the effect with a power of .80. This sample size is quite common in visual search studies examining learning-based transfer. For example, many studies on value-driven attentional capture have used samples of similar size (Anderson et al., 2011; Anderson & Kim, 2018; Grégoire & Anderson, 2019). Those paradigms are closely related to the present design, differing primarily in whether the distractor colors are associated with reward value or with control demands. To allow

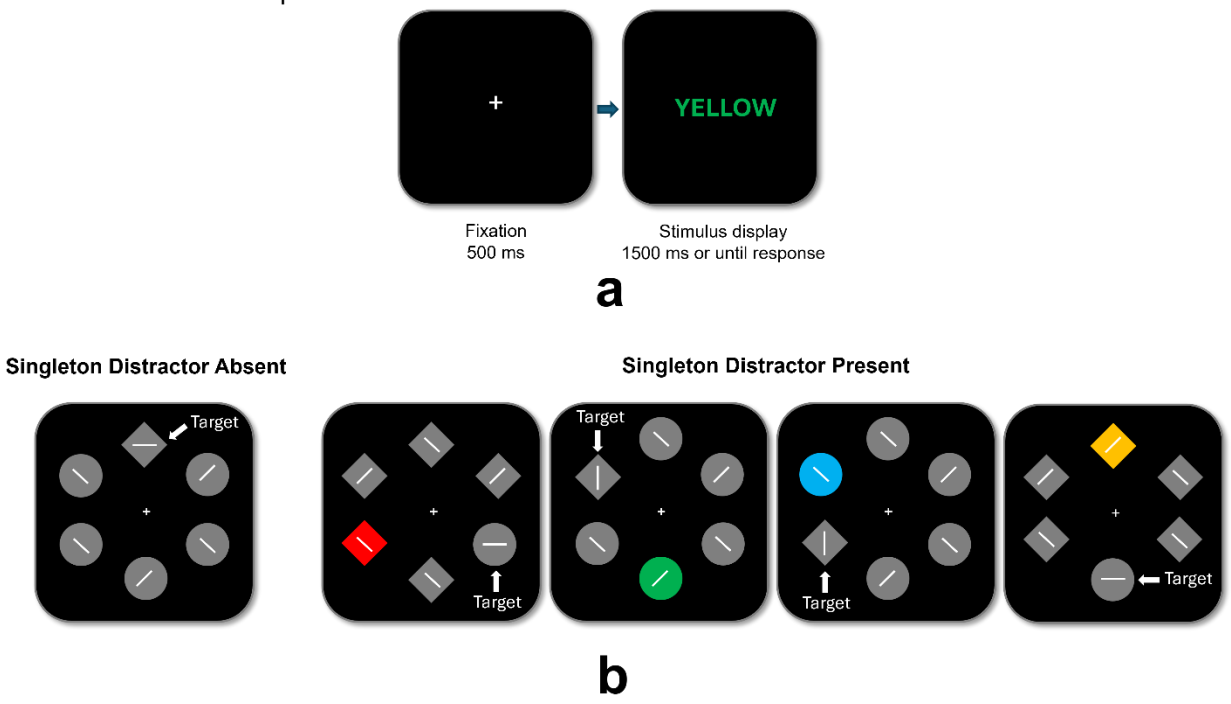
counterbalancing of the conditions, we recruited 24 undergraduate students (6 men and 18 women), who participated for course credit. All participants reported normal or corrected-to-normal visual acuity and normal color vision. Each participant provided informed consent.

Stimuli and Procedure

The experiment was programed in PsychoPy (Peirce, 2007). Stimuli were presented on an LCD monitor against a black background. At the beginning of the experiment, participants were told that they would perform two different tasks in succession. Instructions on each task were given at the start of the task.

Training phase. As shown in Figure 1a, each trial began with a fixation cross (0.5° in height) at the center of the screen for 500 ms, which was then replaced by a color word that was presented in uppercase letters (1.5° in height) at the center of the screen, that was either congruent or incongruent with the color it was displayed in. Participants were required to ignore the meaning of the word but to report what color among the set of {red, green, blue, yellow} the word was displayed in, by pressing one of four corresponding keys on the keyboard (red—“Z”, green—"X”, blue—“N”, yellow—“M”) using the index and middle fingers of both hands. The color word display terminated as soon as a response was made or after 1,500 ms had elapsed without a response. Incorrect or missing responses were followed by an error message, “Incorrect!” or “Too slow!”, respectively, for 500 ms. The next trial started after a 500-ms blank screen intertrial interval. A reminder message of the color-key mapping was displayed at the bottom of the screen throughout the task (0.5° in height).

Figure 1
Stimuli and Task from Experiment 1



Note. (a) Example of trial events in the training phase of Experiment 1. Participants were instructed to name the color of the word and ignore the word meaning. (b) Examples of search arrays in the transfer phase of Experiment 1. Participants searched for a unique shape, either a circle or a diamond (indicated by a label and arrow in the figure that were not shown in the experiment), among homogenous distractors, and reported the orientation of the line (vertical or horizontal) inside the shape. On some trials, one of the non-target shapes appeared in a unique color that was selected from the previously used Stroop task colors {red, green, blue, yellow}. The color singleton distractor was irrelevant to the task, and participants were instructed to ignore it for the best performance.

Transfer phase. Each trial began with a central fixation cross (0.5° in height) for 500 ms, which then remained on the screen accompanying the search array. As shown in Figure 1b, the search array elements were presented along the circumference of an invisible circle (10° in diameter), each separated by 60° of arc. The search array was comprised of either five circles (2.5° x 2.5°) and one diamond (2.2° x 2.2°), or five diamonds and one circle. All shapes were presented in gray, except that on distractor-present trials one of the non-target shapes was presented in a unique color from the set of {red, green, blue, yellow}. Each shape contained a short white line segment (0.7° x 0.05°) at its center. The line in the unique target shape was either vertical or horizontal, while the lines in the other non-target shapes were tilted 45° to the left or right. Participants were required to find the unique target shape on each trial, and

report whether the line segment contained inside that shape was vertical or horizontal by pressing one of two keys on the keyboard (vertical—"F", horizontal—"J"). Additionally, participants were explicitly told that the unique color distractor, when present, was irrelevant to their task and could never be the target, and thus should be ignored. The search array was presented until a response was made or after 1500 ms had elapsed with no response. Incorrect or missing responses were followed by an error message, "Incorrect!" or "Too slow!", respectively, for 500 ms. The next trial started after a 500-ms blank screen intertrial interval. A reminder message of the orientation-key mapping was displayed at the bottom of the screen throughout the task (0.5° in height).

Design

Training phase. For each participant, two of the four Stroop stimulus colors (red, green, blue, and yellow) were the MC colors that were congruent on 75% of the trials; the other two stimulus colors were the MI colors that were incongruent on 75% of the trials. When a color was incongruent, it was equally likely to be paired with each of the other three color words. An example of the stimulus frequencies is illustrated in Table 1. The color-congruency assignment was counterbalanced between participants: For one-half of the participants, red and green were the MC colors, and blue and yellow were the MI colors; for the other participants, the mapping was reversed. Trials were presented in random order. After a 24-trial practice block with the same stimulus proportions as in the actual experiment, participants completed nine blocks of 48 trials each in the training phase.

Table 1
Frequency of Stroop task color-word pairing for the MC and the MI colors in each block (48 trials) of the training phase of Experiments 1-3.

	Color			
Word	Red	Green	Blue	Yellow
RED	9	1	3	3
GREEN	1	9	3	3
BLUE	1	1	3	3
YELLOW	1	1	3	3

Note. In this example, red and green are the MC colors, and blue and yellow are the MI colors. The color-congruency assignment was counterbalanced between participants, with half of the participants receiving this mapping and the other half receiving the reversed mapping.

Transfer phase. On one-third of the trials, all search array elements appeared homogeneously in gray (*color singleton distractor absent* condition); on the other two-thirds of the trials, one of the non-target shapes appeared in a unique color (*color singleton distractor present*). The color singleton distractor equally often appeared in an MC or MI color from the training phase, and also equally often appeared in red, green, blue and yellow. The unique-shape search target was equally often a circle or a diamond, with the non-target elements in the search array being the alternate shape. The location of the target and the color singleton distractor, when present, were randomly selected on each trial. The line segment in the target shape was equally likely to be vertical or horizontal. The line segments in the non-target shapes were pseudo-randomly selected so that approximately one-half of the shapes in each array contained a line tilted to either the left or right direction. The color singleton distractor presence, color singleton identity, target shape identity, and target line orientation were manipulated to be fully crossed with each other. Trials were presented in random order. Before the formal experiment, participants first completed a 12-trial easy practice block with only one target shape displayed on each trial to familiarize them with the line orientation task and the response key mapping; they then completed a second 24-trial practice block with the full design as in the formal experiment. Participants then completed three blocks of 60 trials each in the transfer phase.

Results

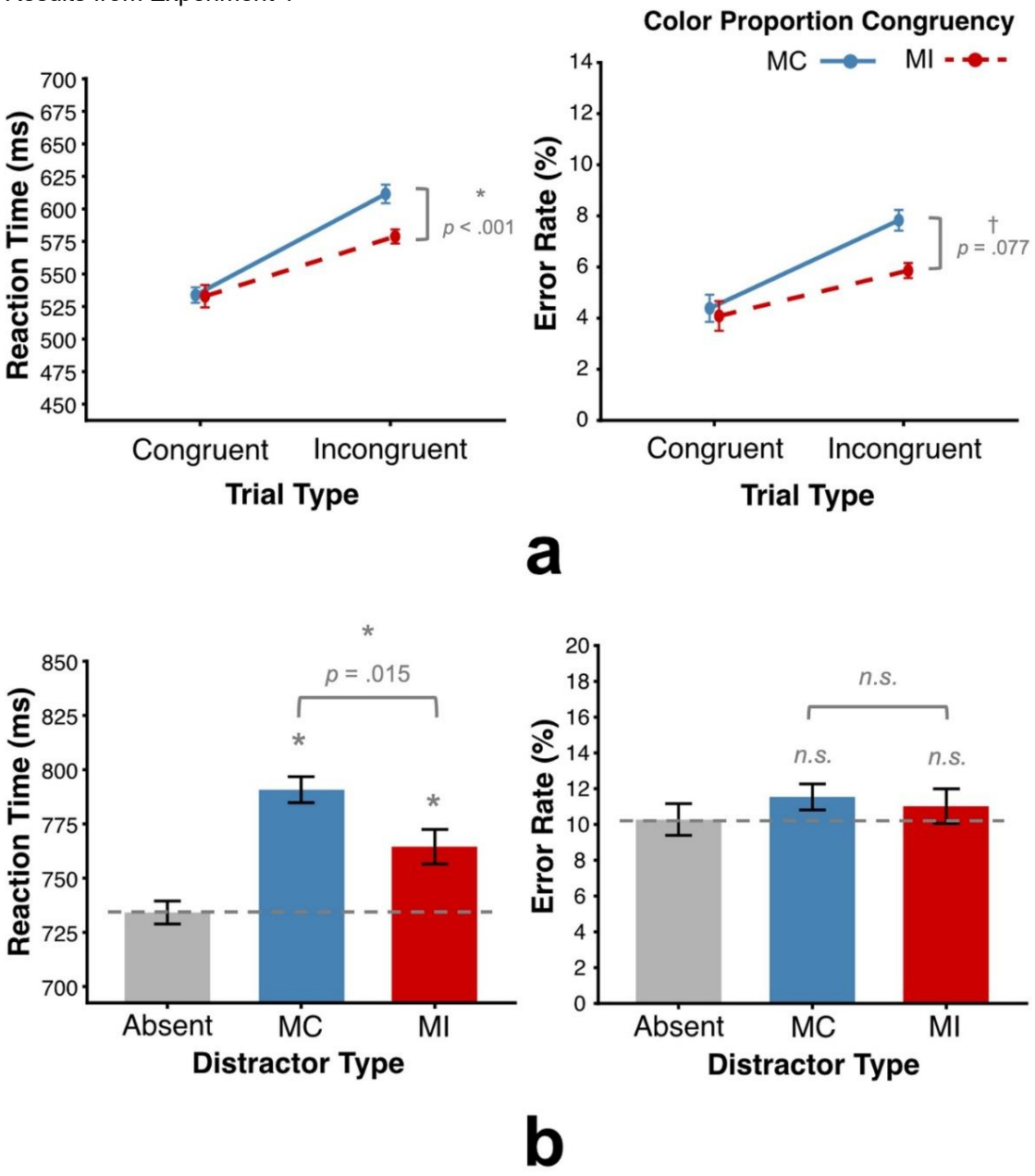
Participants had to achieve an overall accuracy of 70% or greater in both the training and the transfer phases to be included in the analyses. One participant was removed for failing to meet this criterion in the transfer phase. Furthermore, because the transfer of item-specific control must be based on successful acquisition of control in the first place, participants were included in the transfer phase analysis only if they demonstrated evidence of successful ISPC learning as indicated by a numerical ISPC effect in either RT or error rate during the training phase. The same exclusionary criterion was used in earlier studies of ISPC transfer (e.g., Ileri-Tayar et al., 2022, 2024). One participant was removed for not meeting this criterion. This left 23 participants in the training phase analysis and 22 participants in the transfer phase analysis. For each included individual, mean reaction times (RTs) of the cell conditions

were calculated [in the training phase, separately for the four Proportion Congruency (MC vs. MI) x Trial Type (Congruent vs. Incongruent) conditions; in the transfer phase, separately for the MC-color singleton distractor, MI-color singleton distractor, and the color singleton distractor absent conditions]. Trials with RTs more than 2 SDs from each individual's cell mean RTs (3.9% of trials in the training phase; 4.4% of trials in the transfer phase), and trials with incorrect or missing responses were not included in the RT analysis (5.3% of trials in the training phase; 11.0% of trials in the transfer phase).

Training Phase

A 2 Proportion Congruency (MC vs. MI) x 2 Trial Type (Congruent vs. Incongruent) repeated measures ANOVA was conducted on RT. As shown in Figure 2a, there was a significant main effect of trial type, $F(1, 22) = 43.06$, $p < .001$, $\eta_p^2 = 0.66$. Congruent trials (533 ms) had faster RTs than incongruent trials (595 ms). The main effect of proportion congruency was also significant, $F(1, 22) = 6.10$, $p = .022$, $\eta_p^2 = 0.22$. The MI color (556 ms) had faster RTs than the MC color (573 ms). Critically, the interaction between trial type and proportion congruency was significant, $F(1, 22) = 39.73$, $p < .001$, $\eta_p^2 = 0.64$, showing an ISPC effect, validating the effectiveness of training. The congruency effect (RT on incongruent trials minus RT on congruent trials) was larger for the MC color (78 ms difference) than for the MI color (46 ms difference).

Figure 2
Results from Experiment 1



Note. (a) RT (left panel) and error rate (right panel) from the training phase of Experiment 1. The MI color had smaller congruency effects than the MC color in both RT and error rate, suggesting successful ISPC learning. (b) RT (left panel) and error rate (right panel) from the transfer phase of Experiment 1. The previously MI-color distractor yielded a smaller performance cost than the previously MC-color distractor, suggesting goal-based control adaptation when transferring to a novel spatial task. The dash lines represent performance in the singleton absent condition. Error bars represent within-subject standard errors (Cousineau et al., 2021).

The same analysis on error rate produced consistent results. As shown in Figure 2a, the main effect of trial type was significant, $F(1, 22) = 20.77$, $p < .001$, $\eta_p^2 = 0.49$. Congruent trials (4.3%) had a lower error rate than incongruent trials (6.8%). The main effect of proportion congruency was also significant, $F(1, 22) = 10.66$, $p = .004$, $\eta_p^2 = 0.33$. The MI color (5.0%) had a lower error rate than the MC color (6.1%). Additionally, the interaction between trial type and proportion congruency was marginally significant[3], $F(1, 22) = 3.44$, $p = .077$, $\eta_p^2 = 0.14$, showing an ISPC effect. The congruency effect (error rate on incongruent trials minus error rate on congruent trials) was larger for the MC color (3.4% difference) than for the MI color (1.8% difference).

Transfer Phase

RTs on the MC-color singleton distractor trials, MI-color singleton distractor trials, and color singleton distractor absent trials were submitted to a one-way repeated measures ANOVA. As shown in Figure 2b, a significant main effect of condition was found, $F(2, 42) = 18.87$, $p < .001$, $\eta_p^2 = 0.47$. Post-hoc t-tests showed that both the MC-color singleton distractor (791 ms) and the MI-color singleton distractor (764 ms) significantly slowed RT compared to the color singleton distractor absent condition (734 ms), for MC distractor: $t(21) = 5.30$, $p < .001$, $d_z = 1.13$; for MI distractor: $t(21) = 4.63$, $p < .001$, $d_z = 0.99$. Importantly, the MC-color singleton distractor significantly slowed RT more than the MI-color singleton distractor, $t(21) = 2.65$, $p = .015$, $d_z = 0.57$.

Analysis of error rate showed no speed-accuracy tradeoff. The main effect of condition was not significant, $F(2, 42) = 0.54$, $p = .589$, $\eta_p^2 = 0.03$. The MC-color singleton distractor trials (11.5%), MI-color singleton distractor trials (11.0%), and color singleton distractor absent trials (10.3%) all had similar error rates.

Discussion

Experiment 1 investigated whether the attentional control settings learned in an ISPC Stroop task can flexibly transfer to a visual search task. The type of attentional control required in a Stroop task

[3] Throughout the article, effects with $p < .05$ are considered statistically significant (labeled with * in figures), whereas effects with $.05 \leq p < .10$ are described as marginally significant (labeled with †).

involves selection between different information dimensions: filtering irrelevant information (i.e., word reading) while enhancing relevant information (i.e., color naming). The present experiment examined whether this form of dimensional selectivity can transfer to spatial selectivity. Successful visual search similarly requires selective attention, but across locations rather than dimensions, by prioritizing target locations and inhibiting distractor locations. Our results provided evidence for cross-task transfer of item-specific control settings by showing that an MI color distractor, previously associated with a heightened control state in the Stroop task, led to more efficient performance than an MC color, which had been associated with a more relaxed control state. Importantly, the control-associated colors underwent a reversal in task role, shifting from task-relevant during training (Stroop) to task-irrelevant during transfer (visual search). Our finding that an MI-color distractor (relative to an MC color) facilitated, rather than impaired, search performance suggests that learned control was not expressed as perceptual upweighting of the previously high-demand colors. Instead, it reflected a more general state of attentional readiness that could be reconfigured to meet the demands of a new task. This successful adaptation to reversed target–distractor roles indicates that item-specific control was not bound to the original stimulus functions or task context, but could be flexibly recruited to support novel behavioral goals.

Experiment 2

Experiment 1 used an additional singleton task that is known to invoke a singleton-detection mode, under which the search for a salient shape-singleton target tends to incidentally select any salient color singleton distractor (Theeuwes, 1992, 2010; Wang & Theeuwes, 2020). Thus, attentional capture by a distractor in that task is partly caused by the top-down goal of looking for popouts, rather than entirely by the bottom-up salience of the distractor. Such goal-driven attentional selection may have contributed to the transfer of item-specific control in the search task. Although such an occurrence does not weaken the evidence for ISPC transfer observed in Experiment 1, it makes the paradigm less optimal for fully eliminating the task relevance of the control-associated colors. It therefore remains an open question whether cognitive control associated with the Stroop colors would transfer to spatial attentional control when the colors are entirely task irrelevant.

To more cleanly dissociate the control-associated colors from top-down goals in the transfer phase, Experiment 2 used a different visual search task that was designed to disable singleton-detection mode. Following an ISPC Stroop training similar to that in Experiment 1, participants completed a visual search task in which they searched for a prespecified target shape among an array of heterogeneous non-target shapes. All search array stimuli were presented in gray, except on singleton distractor-present trials, in which one of the non-target shapes appeared in a previously MC or MI color. Search tasks like this have been known to invoke a *feature-search mode*, in which attention is guided by specific target features rather than by salience, allowing observers to avoid capture by salient distractors that do not match the target feature (Bacon & Egeth, 1994; Folk et al., 1992). Prior work has shown that with the singleton distractor being fully task irrelevant, its presence often does not impair search performance and can even facilitate it. Because the salient distractor is known never to be the target, observers can rapidly reject it from further consideration, effectively reducing the number of items that must be searched. This more efficient search can produce a *singleton presence benefit*, suggesting successful prevention of detrimental attentional capture (Gaspelin et al., 2015, 2025; Ma & Abrams, 2023b, 2023a, 2025, 2026; Stilwell et al., 2024). Thus, the transfer task in Experiment 2 was expected to minimize attentional selection of the control-associated colors, reducing or potentially eliminating capture, while permitting an assessment of any transfer of cognitive control in the absence of goal relevance. If the presence of an MI color distractor, previously associated with a heightened control state, transfers to recruit stronger spatial attentional control than the MC color, MI-color distractors should be more effectively filtered than MC-color distractors—a pattern conceptually resembling the results of Experiment 1, yet with the now goal-irrelevant distractor being ignored rather than capturing attention. Alternatively, if in an entirely task-irrelevant context the control-associated colors do not transfer to spatial attentional control, the MI and MC distractors should receive a similar level of attention or be ignored to a similar extent.

Method

Participants

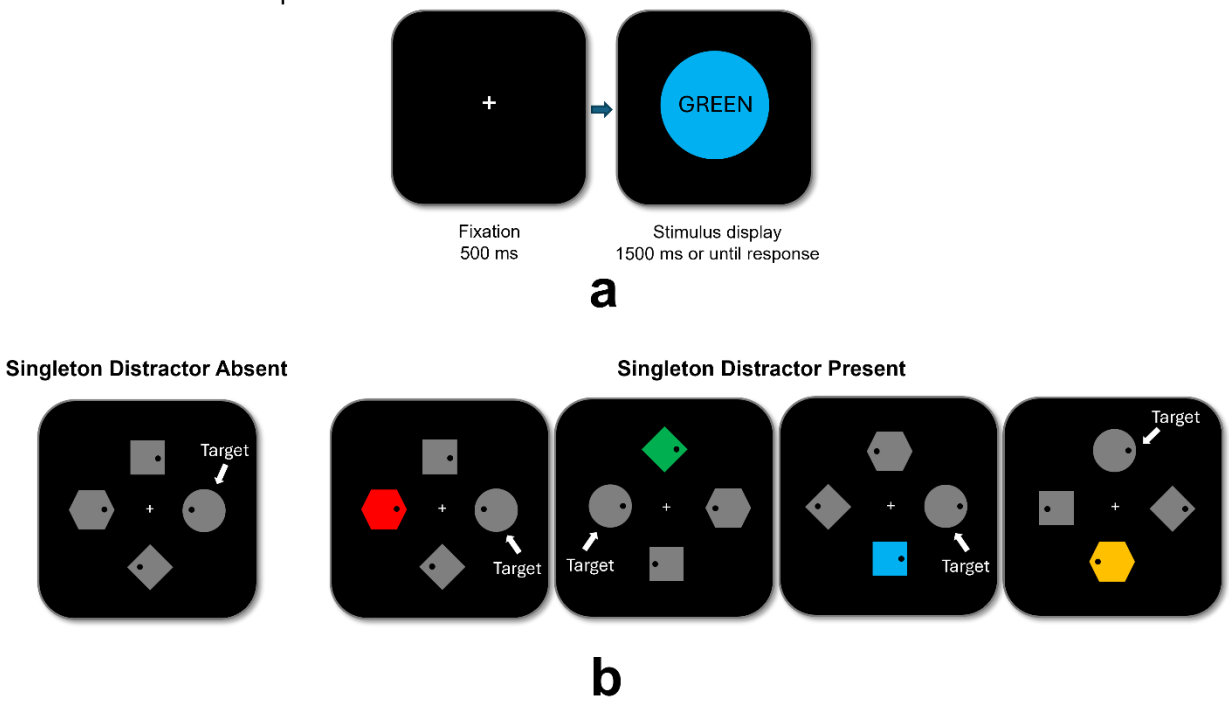
Twenty-four undergraduate students (9 men and 15 women) participated in the experiment for course credit. The same projected sample size (N = 13) of the ISPC Stroop training phase of Experiment 1 applies here. For the transfer phase, because our interest is the comparison between performance in the presence of the MC and MI color distractors, the same projected sample size of the transfer phase of Experiment 1 (N = 25) applies here as well. All participants reported normal or corrected-to-normal visual acuity and normal color vision. Each participant provided informed consent.

Stimuli and Procedure

Training phase. As shown in Figure 3a, the ISPC Stroop task was similar to that of Experiment 1 except that the color word was black and was presented over a colored circle (6° diameter) background (cf. Ileri-Tayar et al., 2022; 2024). Participants were required to name the color of the circle background and ignore the superimposed color word. The same set of colors {red, green, blue, yellow} were used.

Transfer phase. Each trial began with a fixation cross (0.5° in height) for 1000 ms, which then remained on the screen until the offset of the stimulus display. Next, four shapes were displayed 2° above, below, to the left, or right of the fixation. As shown in Figure 3b, the search array consisted of a circle (1.4° x 1.4°), a diamond (1.2° x 1.2°), a square (1.2° x 1.2°), and a hexagon (1.5° x 1.5°). Each shape contained a small black dot (0.2° x 0.2°) positioned 0.5° to the left or right of its center. Participants were instructed to search for a prespecified target shape (a circle or a diamond, for different participants), and report whether the dot inside that shape was on its left or right by pressing the corresponding arrow key on the keyboard. On some trials, all four shapes were presented in gray. On the other trials, one of the non-target shapes was presented in a previously MC or MI color. Participants were told that the color singleton would never be their target shape and thus should be ignored. The search array remained on the screen until a response was made, or after 2000 ms had elapsed without a response. Incorrect or missing responses were followed by an error message, “Incorrect!” or “Too slow!” respectively for 500 ms. The next trial began after a 500-ms blank screen intertrial interval.

Figure 3
Stimuli and Task from Experiment 2



Note. (a) Example of trial events in the training phase of Experiments 2 and 3. Participants were instructed to name the color of the circle and ignore the superimposed color word. (b) Examples of search arrays in the transfer phase of Experiment 2. Participants searched for a prespecified target shape (a circle in this example, or a diamond, counterbalanced between participants, indicated by a label and arrow in the figure that were not present in the experiment), and reported the location of the dot (left or right) inside the shape. On some trials, one of the non-target shapes appeared in a unique color, that was selected from the set of the Stroop task colors {red, green, blue, yellow}. The color singleton distractor was irrelevant to the task and was to be ignored for the best performance.

Design

Training phase. The design of the ISPC Stroop task was identical to that of Experiment 1. After a 24-trial practice block, participants completed six blocks of 48 trials each.

Transfer phase. On one-third of the trials, all search array elements appeared homogeneously in gray (*color singleton distractor absent* condition); on the other two-thirds of the trials, one of the non-target shapes appeared in a unique color (*color singleton distractor present*). The color singleton distractor equally often appeared in a MC or MI color from the training, and also equally often appeared in red, green, blue and yellow. The target shape assignment was counterbalanced between participants: One half of them searched for a circle target; the others searched for a diamond target. When a color

singleton distractor was present, the three non-target shapes were equally often selected as the distractor. The dot inside the target shape was equally often on the left or right, and was equally often congruent or incongruent with the location of the dot inside the color singleton distractor, when present. The locations of the dots inside the other non-target shapes were pseudo randomly selected, such that on each trial two of the four shapes contained a left-side dot, and the other two shapes contained a right-side dot. The locations of the four shapes were randomly selected. Color singleton distractor presence, color singleton distractor color, color singleton distractor shape assignment, the location of the target dot, and its congruency with the color singleton distractor dot were all fully crossed with each other. Trials were presented in random order. After a practice block of 24 trials, participants completed two blocks of 72 trials each in the transfer phase.

Results

Participants had to achieve an overall accuracy of 70% or greater in both the training and the transfer phases to be included in the analyses. All participants met these criteria. Furthermore, for the transfer phase analysis, participants were included only if they demonstrated evidence of successful learning through a numerical ISPC effect in RT or error rate during the training phase. Two participants were removed for no evidence of ISPC learning. This left all 24 participants in the training phase analysis and 22 participants in the transfer phase analysis. For each individual, mean reaction times (RTs) for each condition were calculated [in the training phase, separately for the four Proportion Congruency (MC vs. MI) x Trial Type (Congruent vs. Incongruent) conditions; in the transfer phase, separately for the MC-color singleton distractor, MI-color singleton distractor, and the color singleton distractor absent conditions]. Trials with RTs more than 2 SDs from each individual's cell mean (4.3% of trials in the training phase; 4.1% of trials in the transfer phase), and trials with incorrect or missing responses were not included in the RT analysis (5.6% of trials in the training phase; 1.4% of trials in the transfer phase).

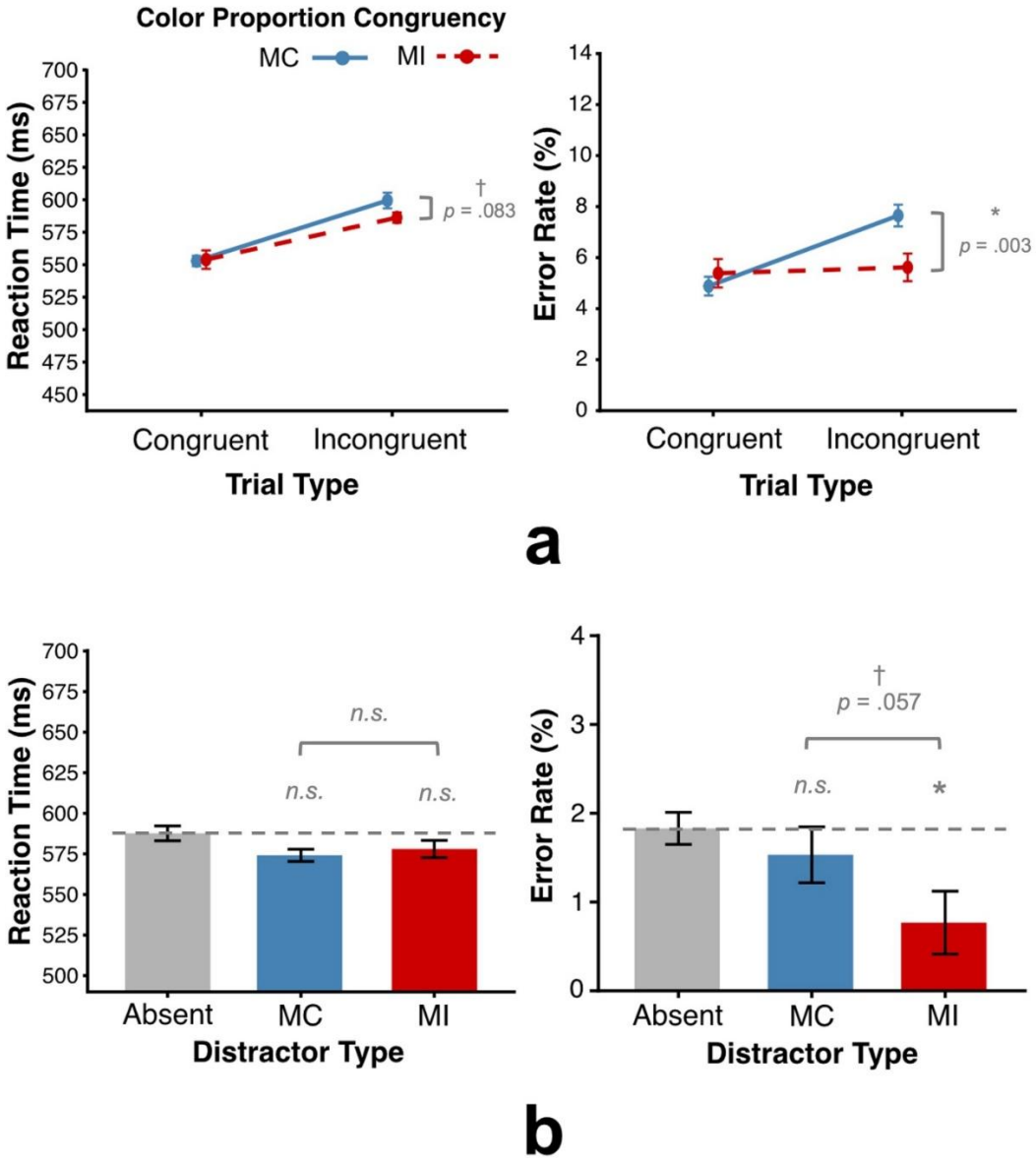
Training Phase

A 2 Proportion Congruency (MC vs. MI) x 2 Trial Type (Congruent vs. Incongruent) repeated measures ANOVA was conducted on RT. As shown in Figure 4a, there was a significant main effect of

trial type, $F(1, 23) = 43.57$, $p < .001$, $\eta_p^2 = 0.65$. Congruent trials (553 ms) had faster RTs than incongruent trials (593 ms). The main effect of proportion congruency was not significant, $F(1, 23) = .97$, $p = .334$, $\eta_p^2 = 0.04$. The MI color (570 ms) and the MC color (576 ms) did not differ overall in RT. The interaction between trial type and proportion congruency was marginally significant, $F(1, 23) = 3.28$, $p = .083$, $\eta_p^2 = 0.13$. The congruency effect (RT on incongruent trials minus RT on congruent trials) was slightly larger for the MC color (47 ms difference) than for the MI color (32 ms difference).

The same analysis on error rate produced stronger results. As shown in Figure 4a, the main effect of trial type was significant, $F(1, 23) = 7.36$, $p = .012$, $\eta_p^2 = 0.24$. Congruent trials (5.1%) had a lower error rate than incongruent trials (6.6%). The main effect of proportion congruency was not significant, $F(1, 23) = 2.50$, $p = .128$, $\eta_p^2 = 0.10$: The MI color (5.5%) and the MC color (6.3%) did not differ in errors. Critically, the interaction between trial type and proportion congruency was significant, $F(1, 23) = 10.66$, $p = .003$, $\eta_p^2 = 0.32$, showing an ISPC effect, validating the effectiveness of training: The congruency effect (error rate on incongruent trials minus error rate on congruent trials) was larger for the MC color (2.7% difference) than for the MI color (0.2% difference).

Figure 4
Results from Experiment 2



Note. (a) RT (left panel) and error rate (right panel) from the training phase of Experiment 2. (b) RT (left panel) and error rate (right panel) from the transfer phase of Experiment 2. The dash lines represent performance in the singleton absent condition. Error bars represent within-subject standard errors (Cousineau et al., 2021).

Transfer Phase

RTs on the MC-color singleton distractor trials, MI-color singleton distractor trials, and color singleton distractor absent trials were submitted to a one-way repeated measures ANOVA. As shown in Figure 4b, the main effect of condition was not significant, $F(2, 42) = 2.32$, $p = .111$, $\eta_p^2 = .10$: The MC-

color singleton distractor present trials (574 ms), the MI-color singleton distractor present trials (578 ms), and the color singleton distractor absent trials (588 ms) did not differ in RT. This result is consistent with effective avoidance of the color singleton distractor.

The same analysis was performed on error rate. As shown in Figure 4b, the main effect of condition was significant, $F(2, 42) = 3.51$, $p = .039$, $\eta_p^2 = .14$. Post-hoc t-tests showed that the presence of the MI-color distractor (0.8%) led to significantly lower error rate than the color singleton distractor absent condition (1.8%), $t(21) = 3.50$, $p = .002$, $d_z = 0.75$, suggesting not only that it had been effectively ignored, but that its presence yielded a target-identification benefit. The presence of the MC-color singleton distractor (1.5%) did not affect the error rate compared to the color singleton distractor absent condition, $t(21) = 0.57$, $p = .577$, $d_z = 0.12$. The presence of the MI-color singleton distractor also led to marginally significantly lower error rate than the MC-color singleton distractor, $t(21) = 2.01$, $p = .057$, $d_z = 0.43$.

Discussion

Experiment 2 used a visual search task that encouraged a feature-search mode and thereby minimized goal-directed attentional selection of salient distractors. This paradigm more fully eliminated the task relevance of the previously control-associated color. Nevertheless, the MI and MC distractors produced numerically different levels of interference during visual search. Both distractor colors produced numerically faster RTs and lower error rates relative to the distractor-absent baseline, suggesting successful attentional filtering of the distractors rather than attentional capture by them. In addition, the MI-color distractor produced significantly lower error rates than the distractor-absent condition and was marginally more effectively filtered than the MC-color distractor. This enhanced filtering of the MI-color distractor reflects stronger goal-directed spatial selectivity, indicating successful cross-task transfer of item-specific control. Thus, Experiment 2 replicated the findings of Experiment 1, but with the transfer effect manifested as distractor filtering rather than attentional capture when the search context allowed distractors to be ignored. As in Experiment 1, perceptual enhancement of the MI colors would otherwise have led to an opposite pattern of results. Thus, the present findings consistently

suggest that the cognitive control underlying ISPC effects is represented in an abstract form of attentional readiness that can flexibly adapt to new task demands, rather than low-level perceptual upweighting of the specific control-associated colors.

It is also noteworthy that the critical effects in both the training and transfer phases emerged primarily in error rates rather than RTs. Because speed and accuracy can trade off against one another, this pattern suggests that participants may have adopted a response strategy that emphasized speed, possibly responding under implicit time pressure. Under such conditions, experimental effects are more likely to appear in accuracy than in response latency. Importantly, regardless of whether the effects emerged in RT or error rate, they reflect the same underlying modulation of attentional control.

Experiment 3

Experiments 1 and 2 both showed reduced search efficiency in the presence of an MC-color distractor. These findings support the view that the control mechanisms underlying the ISPC effect can adapt to novel task demands in a goal-based manner, rather than merely reflecting a carryover of perceptual priming. Although the preceding results support a goal-based control adaptation account, they leave open the specific attentional mechanisms through which this adaptation influences visual search. Because the findings from Experiments 1 and 2 were based solely on overall search efficiency and accuracy, they cannot indicate whether the control-associated colors actually biased spatial attention or instead produced a global performance cost without influencing attentional allocation. In particular, one possibility is that the heightened control associated with MI colors facilitated goal-directed attentional selection that filters distractors, such that attention was either captured by MI-colored distractors less often or disengaged from them more rapidly than from MC-colored distractors. Alternatively, the presence of an MI color may have enhanced overall attentional readiness without biasing spatial attention, globally benefiting search performance—for example, by reducing filtering costs or promoting a more efficient search process (see Becker, 2007; Lavie & Tsal, 1994). Both accounts would reflect successful transfer of item-specific control from a Stroop task to spatial attentional control, yet the transfer of control would have been accomplished by very different mechanisms: enhanced spatial selectivity versus

improved overall processing efficiency. Our goal in the present experiment was to distinguish between these possibilities.

Experiment 3 used a cued visual search task that permitted the assessment of attentional deployment to each stimulus location. Following an ISPC Stroop training phase (identical to Experiment 2), participants performed a visual search task in which two task-irrelevant color cues were briefly presented, each marking one of the two locations of a two-letter search array. On each trial, one location was cued with a previously MC or MI color, while the other location was cued with a neutral gray color. The cues were uninformative with respect to the subsequent target location: on 50% of trials, the target appeared in the location of the MC/MI color cue, and on the remaining 50% of trials, it appeared in the location of the gray cue. Under this design, the previously control-associated colors that were the to-be-attended dimension during the Stroop training, again reversed their functional roles and became to-be-ignored distractors during transfer. Cueing paradigms like this have been commonly used to assess attentional allocation: If attention is captured by a cue, target identification should be better when the target appears in the cued location (i.e., valid condition) compared to the uncued location (i.e., invalid condition; e.g., Jonides, 1981; Meyer et al., 2020; Posner, 1980). Performance differences between the two types of trials—the cue validity effect—index the degree of attentional capture. Therefore, if the heightened control demands associated with an MI color transfers as spatial selectivity that filters irrelevant distractors, an MI-color cue should capture attention less than a MC-color cue, producing smaller cue validity effects. Alternatively, if the transfer instead reflects a generally more efficient search process triggered by the heightened control demands associated with MI-color cues, then the MI-color cues should lead to overall faster RTs than MC-color cues, without affecting the size of the cue validity effect. Finally, consistent with Experiments 1 and 2, the present experiment also tested whether the ISPC effect transfers through feature-based priming of the control-associated colors. Under this account, the MI color, which received greater attentional weighting during Stroop training, should produce a larger cue-validity effect than the MC color.

Method

Participants

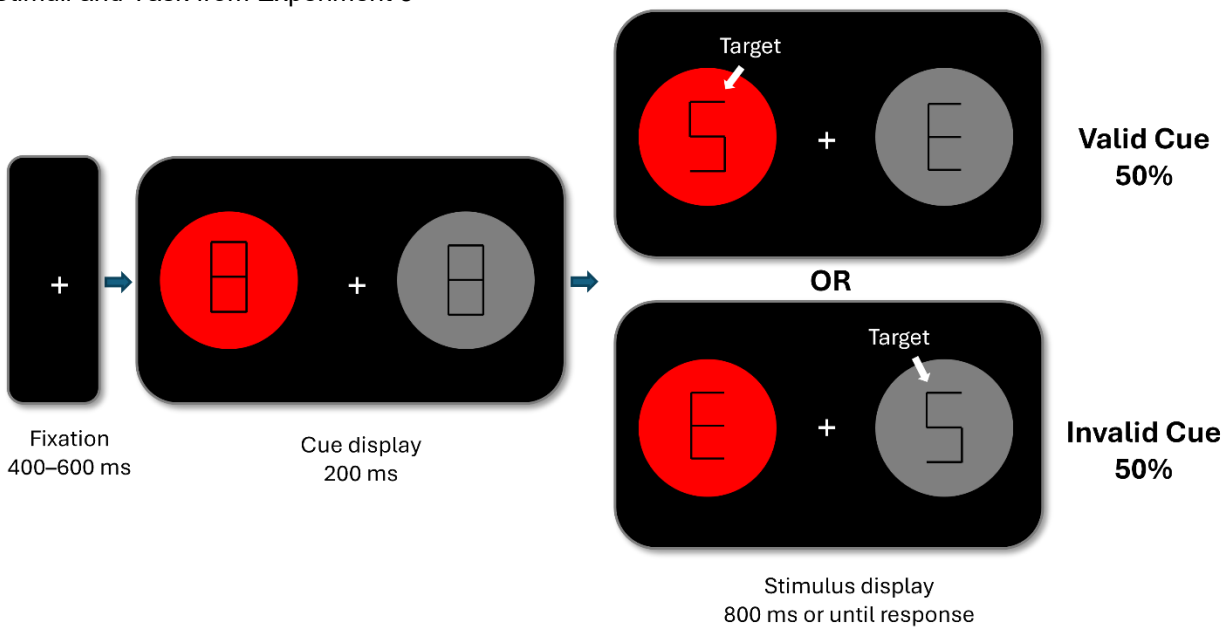
Forty-nine undergraduate students (11 men and 38 women) participated in the experiment for course credit. The same projected sample size (N = 13) for the ISPC Stroop training phase of Experiment 1 applies here. For the cueing task in the transfer phase, of critical interest is the interaction between Cue Proportion Congruency (MC vs. MI) and Cue Validity (Valid vs. Invalid). As no prior study on the transfer of the ISPC effect examined its interaction with a second new variable, we did not have an estimated effect size for power analysis but aimed to double the projected sample size of Experiment 1 (N = 25). All participants reported normal or corrected-to-normal visual acuity and normal color vision. Each participant provided informed consent.

Stimuli and Procedure

Training phase. The ISPC Stroop training was identical to that of Experiment 2.

Transfer phase. As shown in Figure 5, each trial began with a central fixation cross (0.5° in height) for a variable duration of 40–600 ms. Next, two colored circles (6° diameter) appeared, 10° to the left and right of fixation. One circle was presented in a previously MC or MI color, and the other circle appeared in gray. Each circle contained a black number “8” placeholder in DS-Digital font (2.3° x 1.1°) for 200 ms, which then changed into a letter from the set of {“E”, “H”, “S”, “P”} by removal of some segments. Participants were required to indicate whether the letter “S” or “P” was present on each trial by pressing the corresponding letter key on the keyboard. They were explicitly told that the color of the circles was irrelevant to their task. The circles and the letters disappeared as soon as a response was made, or after 800 ms if there was no response. Incorrect or missing responses were followed by an error message, “Incorrect!” or “Too slow!”, respectively, for 500 ms. The next trial started after a 500-ms blank screen intertrial interval.

Figure 5
Stimuli and Task from Experiment 3



Note. Example of trial events in the transfer phase of Experiment 3. Participants were required to report whether a letter "S" or "P" was presented on each trial (indicated by a label and arrow in the figure that were not present in the experiment). One of the two circles on each trial appeared in a previously trained MC or MI color, which was uninformative of the target location.

Design

Training phase. The design of the ISPC Stroop task was identical to that of Experiment 1. After a 24-trial practice block, participants completed six blocks of 48 trials each.

Transfer phase. On each trial, one of the two circles appeared equally often in a previously MC or MI color from training, and was also equally often in red, green, blue, or yellow. The color of the circles was uninformative of the target location: The target letter appeared in the colored circle on one-half of the trials (*valid cue* condition), and in the gray circle on the other trials (*invalid cue* condition). The circle in the previously trained color appeared equally often on the left or right side of the screen; the same was true for the target letter. Letters "S" and "P" were equally often selected as the target letter, and the non-target letter was equally often an "E" or "H". Each target letter was equally often paired with each non-target letter. The color of the cue circle, the validity of the cue, the target letter and target location were manipulated to be fully crossed with each other. Trials were presented in random order. After a 24-trial practice block, participants completed two blocks of 64 trials each in the transfer phase.

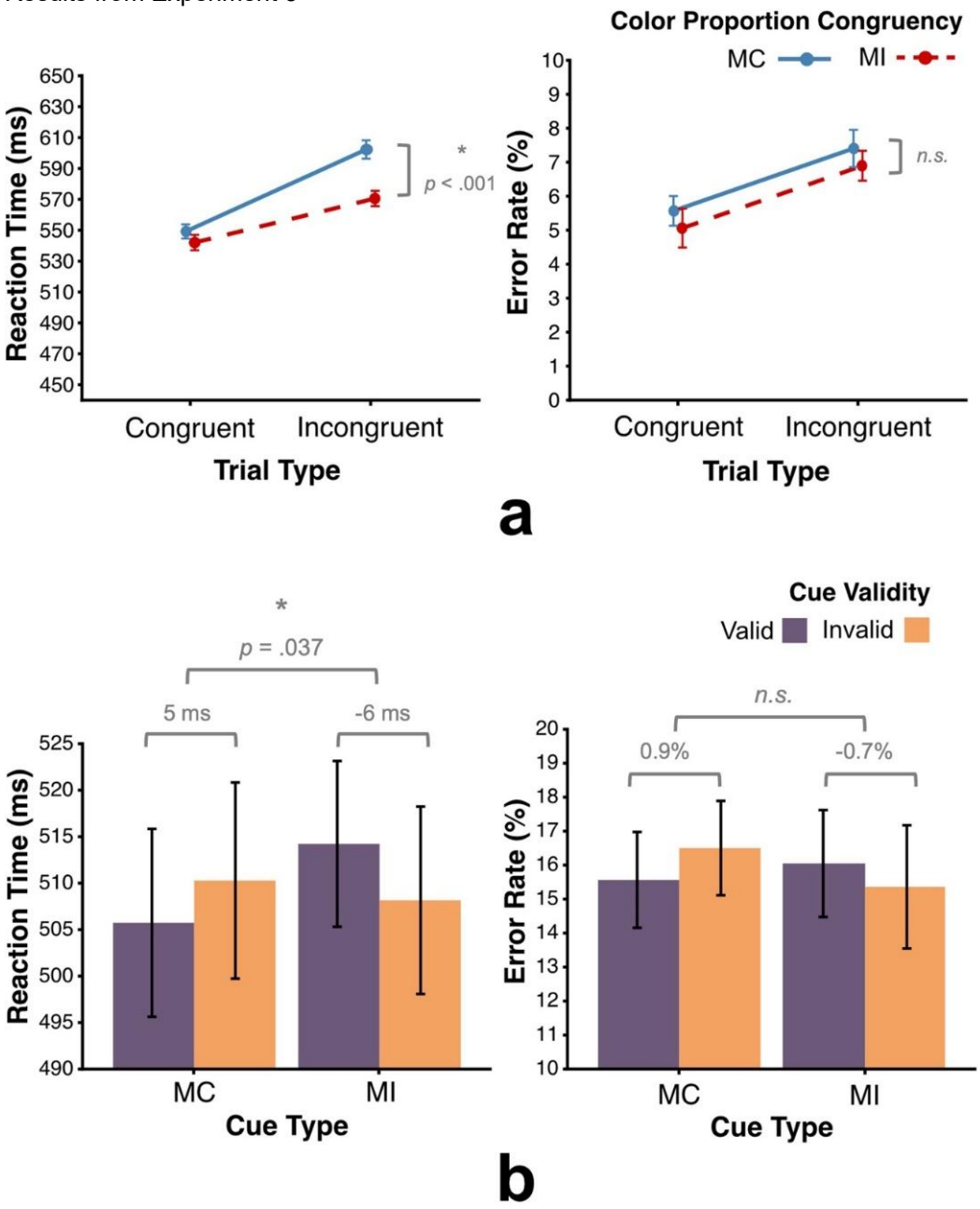
Results

Participants had to achieve an overall accuracy of 70% or greater in the training phase and 70% or greater in the transfer phase to be included in the analyses. Ten participants were removed for failing to meet this criterion in the transfer phase. Furthermore, for the transfer phase analysis, participants were included only if they demonstrated evidence of successful learning through a numerical ISPC effect in RT or error rate in the training phase. Six additional participants were removed for no evidence of ISPC learning. This left 39 participants in the training phase analysis and 33 participants in the transfer phase analysis. For each remaining individual, mean reaction times (RTs) of the cell conditions were calculated [in the training phase, separately for the four Proportion Congruency (MC vs. MI) x Trial Type (Congruent vs. Incongruent) conditions; in the transfer phase, separately for the four Cue Proportion Congruency (MC vs. MI) x Cue Validity (Validity vs. Invalid) conditions]. Trials with RTs more than 2 SDs from each individual's cell mean RTs (4.3% of trials in the training phase; 2.0% of trials in the transfer phase), and trials with incorrect or missing responses were not included in the RT analysis (6.2% of trials in the training phase; 15.9% of trials in the transfer phase).

Training Phase

A 2 Proportion Congruency (MC vs. MI) x 2 Trial Type (Congruent vs. Incongruent) repeated measures ANOVA was conducted on RT. As shown in Figure 6a, there was a significant main effect of trial type, $F(1, 38) = 95.24$, $p < .001$, $\eta_p^2 = 0.72$. Congruent trials (546 ms) had faster RTs than incongruent trials (586 ms). The main effect of proportion congruency was also significant, $F(1, 38) = 6.66$, $p = .014$, $\eta_p^2 = 0.15$. The MI color (556 ms) had faster RTs than the MC color (576 ms). Critically, the interaction between trial type and proportion congruency was significant, $F(1, 38) = 30.61$, $p < .001$, $\eta_p^2 = 0.45$, showing an ISPC effect, validating the effectiveness of training. The congruency effect (RT on incongruent trials minus RT on congruent trials) was larger for the MC color (53 ms difference) than for the MI color (29 ms difference).

Figure 6
Results from Experiment 3



Note. (a) RT (left panel) and error rate (right panel) from the training phase of Experiment 3. The MI color produced a significantly smaller congruency effect than the MC color in RT, suggesting successful ISPC learning. (b) RT (left panel) and error rate (right panel) from the transfer phase of Experiment 3. The MC-color cue produced a significantly greater cue validity effect than the MI-color cue, suggesting greater spatial attentional allocation to the MC color. Error bars represent within-subject standard errors (Cousineau et al., 2021).

The same analysis was conducted on error rate. The main effect of trial type was not significant, $F(1, 38) = 22.23$, $p < .001$, $\eta_p^2 = 0.37$. Congruent trials (5.3%) had lower error rate than incongruent trials

(7.2%). The main effect of proportion congruency was not significant, $F(1, 38) = 0.62$, $p = .436$, $\eta_p^2 = 0.02$. The interaction between trial type and proportion congruency also was not significant, $F(1, 38) < .01$, $p = .998$, $\eta_p^2 = 0.00$. The congruency effect (error rate on incongruent trials minus error rate on congruent trials) did not differ between the MC color (1.8% difference) and the MI color (1.8% difference).

Transfer Phase

A 2 Cue Proportion Congruency (MC vs. MI) x 2 Cue Validity (Valid vs. Invalid) repeated measures ANOVA was conducted on RT. As shown in Figure 6b, the main effect of cue validity was not significant, $F(1, 32) = .05$, $p = .821$, $\eta_p^2 = 0.00$. Targets appearing at the cued location (510 ms) and the uncued location (509 ms) did not differ in RT. The main effect of cue proportion congruency also was not significant, $F(1, 32) = .82$, $p = .371$, $\eta_p^2 = 0.03$. The MI color (511 ms) and the MC color (508 ms) conditions did not differ in RT. However, critically, the interaction between cue validity and cue proportion congruency was significant, $F(1, 32) = 4.73$, $p = .037$, $\eta_p^2 = 0.13$, indicating a difference in attentional capture by the two types of cues that depended on proportion congruency from the training phase: The cue validity effect (RT on invalid trials minus RT on valid trials) was positive for the MC color (5 ms difference), indicating attentional capture, but surprisingly it was negative for the MI color (-6 ms difference). Despite being uninformative regarding the target location, the MC-color cue attracted attention more strongly than the MI-color cue.

The same analysis on error rate showed no speed-accuracy tradeoff. As shown in Figure 6b, the main effect of cue validity, the main effect of cue proportion congruency, and the interaction between the two were all not significant, Fs < 1. Notably, despite not being significant, the error rate results showed a performance pattern numerically resembling the RT results—the cue validity effect was positive for the MC color (0.9%) but was negative for the MI color (-0.7%).

Discussion

Experiment 3 conceptually replicated the ISPC transfer effect from Stroop training to spatial attentional control observed in Experiments 1 and 2, and extended those findings by showing that the

effect reflects differences in attentional deployment to the locations of the MC and MI colors, rather than changes in global filtering costs or the general efficiency of visual processing in the presence of the colors. The use of the cued visual search task in the transfer phase permitted examining attentional allocation to cues whose colors were previously associated with different levels of control. The significant interaction between cue validity and cue proportion congruency in RT revealed a difference in the amount of attention allocated to the MC and MI color cues. The MC-color cue, that was associated with a more relaxed control setting, had a positive cue validity effect, suggesting that despite being uninformative of the target location, it was more likely to capture attention. On the contrary, the MI-color cue, that was associated with a more heightened control setting, had a reversed cue validity effect, suggesting that it did not capture attention, but conversely was avoided to an extent. These results suggest that the transfer of item specific control influenced spatial selectivity rather than overall processing efficiency. In addition, consistent with Experiments 1 and 2, the finding that the MI-color cue was better ignored than the MC-color cue suggests that the control mechanisms underlying the ISPC effect can adapt to novel task demands in a goal-based manner, rather than merely reflecting a carryover of perceptual priming.

One potential limitation of Experiment 3 is that the use of a letter identification task in the transfer phase required word (or letter) reading to an extent, which in the Stroop training phase happened to be a filtered process. Jacoby et al. (1999, 2003) considered the possibility that the control mechanism in a Stroop task could be a word-reading filter: Due to the irrelevant and distractive nature of the color word meaning, an observer would benefit in the task by filtering out any semantic information in order to suppress inappropriate response tendencies due to word reading. Under the ISPC manipulation, in this view, the MC colors would have been associated with weaker filtering of word-reading responses than the MI colors (but see counter evidence in Keha & Bugg, in press). This introduces some ambiguity in interpreting the cueing results: the reduced cue validity effect for MI colors could reflect either reduced attentional allocation to the cued location or impaired processing of the letter following attentional selection. Nevertheless, several studies on ISPC transfer challenge the notion of a conflict-specific filter by showing that learned control generalizes across tasks with distinct filtering demands (e.g., Ileri-Tayar

et al., 2022, 2024). More importantly, the present findings demonstrate transfer despite the control-associated colors going through a target-to-distractor role reversal from the training to transfer phase, making a schematic carryover of a word-reading filter unlikely.

General Discussion

The present study examined whether learned item-specific control settings from a Stroop task transfer to the control of spatial attention in visual search tasks—the farthest form of transfer investigated to date in the item-specific control literature. By presenting the Stroop colors that were previously associated with varying attentional demands (MC—low; MI—high) and learned control settings (MC—relaxed; MI—heightened) as explicitly designated task-irrelevant distractors during visual search, the study also tested competing hypotheses regarding the locus of transferred control. One hypothesis was that perceptual enhancement of MI colors, which would benefit Stroop performance, would lead to detrimental attentional capture by those colors during visual search. An alternative hypothesis was that enhanced central cognitive control in the presence of MI colors would adapt to the new goal and thus predict more effective distractor filtering and reduced attentional capture. Experiment 1 used an additional singleton task, in which attention tends to be captured by a color singleton distractor (Theeuwes, 1992). The MC-color distractor, which was previously associated with weaker control demands, was found to disrupt the search to a greater extent than the MI-color distractor. Experiment 2 used a specific-target visual search task that permits ignoring of salient distractors. Conceptually replicating Experiment 1, the MC-color distractor again produced greater interference than the MI-color distractor. Experiment 3 used a cued visual search task and confirmed that attention was attracted to the location of the MC color more strongly than the MI color, further pinpointing that the heightened control setting associated with the MI color benefitted goal-directed spatial attentional selection rather than improving general efficiency in visual processing (Gaspelin et al., 2015; Oxner et al., 2022). Together, our experiments provide converging evidence that attentional control involved in information dimension selection during Stroop tasks can transfer to the control of spatial location selection.

Notably, with the functional roles of the control-associated colors reversed from a to-be-attended target dimension during Stroop training to to-be-ignored distractors during transfer, learned item-specific control successfully reconfigured to meet the new task goals, modulating attentional deployment accordingly by facilitating the selection of relevant items and suppressing attention to irrelevant distractors. This flexible adaptation to changing task demands—attentional filtering of previously prioritized colors—supports a generalized control representation that can be recruited beyond the specific stimulus functions and attentional demands under which it was learned.

The present study is the first one to examine the transfer of the control settings across novel stimuli, dissimilar contexts, distinct types of control demands, and even competing task goals. Existing studies have demonstrated cross-stimulus and cross-task transfer of item-specific control, but have focused on paradigms in which conflict ultimately arises from competing sources of task-relevant and task-irrelevant information at response selection (Bugg & Hutchison, 2013; Colvett et al., 2025; Ileri-Tayar et al., 2022, 2024). The present study demonstrates a significantly greater malleability of the transfer of control. Our findings demonstrating differences in spatial attentional allocation to the previously MC and MI colors suggest that item-specific control can transfer from information dimension selection to resolve novel conflicts in spatial location selection. Specifically, the control that previously suppressed dominant but nonessential information in the Stroop task transferred to the inhibition of salient but to-be-ignored spatial distractors. These findings demonstrate that item-specific control arises from a flexible, generalizable cognitive mechanism that operates across distinct forms of attentional selection, extending beyond stimulus- or task-specific learning.

Item-Specific Control Operates via a Cognitive, Not Perceptual, Mechanism

The transfer of item-specific control can be interpreted through the episodic retrieval account of cognitive control (Brosowsky & Crump, 2018; Bugg & Crump, 2012; Crump & Milliken, 2009). According to this account, experiences are encoded as *event files* that bind stimulus features with associated responses, contextual information, and internal control states (Dignath et al., 2019; Egner, 2014; Hommel, 2004). In the ISPC Stroop task, repeated encounters with each color establish associations

between that color, its history of conflict, and the control setting most frequently recruited to resolve that conflict. Specifically, MC colors become associated with relatively low conflict and relaxed control, whereas MI colors become associated with frequent conflict and heightened control. Subsequent encounters with these colors can then retrieve their associated control states, allowing control to be adjusted based on prior experience (Bugg & Crump, 2012; Crump & Milliken, 2009). From this perspective, the ISPC effect reflects the encoding and subsequent retrieval of item-specific control states. Previous studies of transfer of item-specific control (Bugg & Hutchison, 2013; Ileri-Tayar et al., 2022) suggest that the retrieval of the episodic file is not task-specific, as the learned control settings can be recruited to resolve similar conflicts under novel task demands. And more broadly, our findings of the cross-task transfer of item-specific control shows that even when the control-associated colors are reencountered in a task context in which the goal is to spatially locate a target, and the colors appeared as spatial distractors with no relevance to the task goal, they nevertheless triggered retrieval of the learned control settings. Importantly, by pinpointing the locus of control at a cognitive rather than perceptual level, our findings further suggest that item-specific cognitive control operates between stimuli and high-level task goals, rather than between stimuli and low-level environmental features or specific responses.

Previous research has not identified the level at which item-specific control operates to enable its transfer across tasks. Studies on the cross-stimulus transfer of the effect preliminarily suggest the possibility of a "conflict-specific" filter that resolves conflicts of a particular prototype. For example, Bugg and Hutchison (2013) considered the possibility that stringent and lenient word-reading filters were separately invoked by colors of high and low control demands (Jacoby et al., 1999, 2003), so that the MI color can be better shielded from the interference of novel incongruent words. This explanation, however, was later challenged by the studies of cross-context transfer: The Stroop and flanker tasks used in Ileri-Tayar et al. (2022) require different conflict-resolution schemes (semantic filtering vs. spatial filtering), which could not easily be accomplished by a carryover of conflict-specific filters. Nevertheless, a filtering mechanism cannot be fully ruled out, as repetition of task goals may have inflated the transfer effect; notably, the modified flanker task in that study still required color naming as in the Stroop task. More

importantly, past studies always presented the control-associated colors as the target of the task in both the training and transfer phases (see produce naming task as an exception, though one in which color was arguably still relevant; Ileri-Tayar et al., 2024), leaving open the possibility of a general filtering mechanism that indiscriminately suppresses all (irrelevant) information other than the color. In the present study, such a filtering mechanism would not have yielded the transfer that we observed because the control-associated colors were to-be-filtered items during the transfer task. The finding that colors associated with greater control demands were conversely more effectively filtered thus rules out the possibility of a stimulus-specific filtering mechanism. Instead, our findings provide evidence consistent with a higher-level, goal-based mechanism of item-specific control.

Other associative learning mechanisms proposed to contribute to ISPC effects also appear insufficient to fully explain the present transfer findings. One possibility is *contingency learning*, whereby participants learn associations between particular stimuli and their likely responses rather than retrieving different control settings (Schmidt & Besner, 2008; see also Bugg et al., 2011). However, the stimulus–response contingencies acquired during Stroop training were no longer useful during visual search, where the previously predictive colors became task-irrelevant distractors and required entirely different responses. Similarly, *episodic retrieval of responses* associated with previous encounters with a stimulus has been proposed to contribute to proportion-congruency effects (Gallego et al., 2025; Rothermund et al., 2022), but cannot readily explain why encountering an MI color facilitated performance when the responses previously associated with that color were no longer relevant. Finally, *short-term repetition priming* has also been shown to contribute to ISPC effects (Cochrane & Pratt, 2021), but simple enhancement of previously repeated stimulus features would not readily explain the goal-appropriate benefit observed when those features became task-irrelevant distractors.

Item-Specific Control Is Automatic

The transfer of item-specific control between highly dissimilar tasks to serve disparate task goals implies an automatic nature of the control. Automaticity is characterized by the efficiency and effortlessness of a process that has minimal occupation of attentional capacity, and can operate with other

automatic processes in a parallel manner (Moors & De Houwer, 2006). Prior demonstrations of cross-stimulus and cross-task transfer have been interpreted as evidence that, once a control-associated color is processed, its associated control setting can be retrieved and executed automatically despite changes in the surrounding context (e.g., Bugg & Hutchison, 2013; Ileri-Tayar et al., 2022, 2024; Ileri-Tayar, Suh, et al., 2025; Suh & Bugg, 2021). Importantly, this account does not require processing of the predictive cue itself to be automatic; rather, automaticity concerns the retrieval and execution of control triggered once that cue is processed. The present study extends this evidence by showing transfer when the control-associated colors were no longer task-relevant targets but instead to-be-ignored distractors, while responses were entirely unrelated to color. Despite this reversal in their task role, processing of the colors was sufficient to trigger their associated control settings, which were then recruited in accordance with the new task demands. This occurred even in Experiment 2, in which color distractors were effectively suppressed, sometimes producing performance better than the distractor-absent baseline and therefore suggesting minimal attentional allocation to the distractors. Thus, the present findings are consistent with the automatic retrieval and execution of learned control settings following processing of a predictive cue, and extend this automaticity to conditions in which the cue is task-irrelevant and the retrieved control must be applied toward a substantially different task goal.

Early, Attention-Independent Triggering of Item-Specific Control

The present findings provide novel evidence that control-signaling stimuli do not need to be explicitly attended for retrieval of control settings to occur. In Experiments 2 and 3, MI colors were actively suppressed, with Experiment 2 showing suppression below baseline such that the presence of distractors in a previously MI color did not impair, and even facilitated, performance. Despite this limited attentional allocation, control transfer was still observed, indicating that focused attentional selection of a control-associated stimulus is not a prerequisite for triggering its learned control setting. This extends previous demonstrations of item-specific control, in which predictive cues were generally task-relevant and therefore received substantial attentional processing, by showing that control can be triggered even when the predictive cue itself is subject to attentional suppression. Thus, relatively early perceptual

registration of a control-associated feature may be sufficient to retrieve its learned control setting without that feature being fully selected by attention.

Moreover, the present findings suggest that this triggering occurs sufficiently early to influence subsequent attentional selection. In Experiment 3, attention was less frequently allocated to locations cued by MI than MC colors, suggesting that the control associated with an MI color was triggered early enough to prevent initial shifts of attention from being directed toward its location. Thus, learned control may be invoked at an early stage of information processing, allowing the control associated with a stimulus to shape its subsequent attentional selection rather than operating only after that stimulus has already been selected.

Carryover of Perceptual versus Cognitive Effects

The present study demonstrates cognitive control transferring at a higher-order, goal-based level, in contrast to many studies of visual attention that have demonstrated carryover of perceptual, feature-based priming. Such perceptual effects reflect nonvolitional continuation driven by prior attentional selection (i.e., *selection history*; Awh et al., 2012; Wolfe, 2019), which can operate counter to current top-down goals. For example, in studies of value-driven attentional capture, colors associated with monetary reward continue to capture attention in subsequent, unrelated tasks even after reward associations are no longer relevant (Anderson et al., 2011; Anderson & Kim, 2018; Grégoire & Anderson, 2019; Ma & Abrams, 2022). This form of capture occurs even when reward-associated stimuli are merely task-irrelevant distractors, illustrating how selection history can override current task goals (Anderson et al., 2011, 2012; Anderson & Yantis, 2013). Other studies similarly show that attention is biased toward previously attended locations or features, with effects that can persist across trials despite changes in task relevance (Lamy et al., 2006; Lamy & Kristjánsson, 2013; Maljkovic & Nakayama, 1994; Talcott et al., 2022; Talcott & Gaspelin, 2020). Together, these findings highlight the robustness of habitual, non-volitional influences on attentional selection. In contrast, the present study shows the opposite pattern: MI colors that previously demanded more attention were instead more effectively ignored under a new task

goal, indicating that control operates at a higher-order cognitive level that can flexibly adapt to the new task goals and override competing influences of selection history.

Relation to Statistical Learning in Visual Search

The present results are also more generally related to studies which have shown that people are sensitive to a variety of different environmental regularities that provide information about likely target or distractor locations or attributes during visual search. Such *statistical learning* can be used to guide subsequent behavior. For example, Chun and Jiang (1998) showed that people were sensitive to the spatial locations of distractor items when those locations predicted where the target might be. And Siegel and Abrams (2025) showed that people learn about likely target locations in a reference frame that is not anchored to a specific spatial location. Other studies have shown that people can learn to ignore likely distractor features or locations through exposure to statistical regularities about the distractors (Stilwell et al., 2019; Vatterott & Vecera, 2012; Wang et al., 2019; Wang & Theeuwes, 2018). Similarly, the present study and previous ones on ISPC transfer have shown that people are able to learn about the cognitive control demands associated with environmental features and can then use that learning to guide behavior in new tasks. The present study extends these findings by showing a remarkable generalizability of item-specific control, whereby learned regularities can guide behavior across highly distinct task contexts and control demands. Taken together the results highlight a flexible system that engages in a variety of different types of learning to aid in performance of a range of different tasks.

Conclusions

The present experiments have shown that item-specific cognitive control invoked by colors in a Stroop task can be re-invoked by those same colors during a subsequent visual search task, despite novel task requirements and distinct control demands. The findings reveal a remarkable flexibility of the cognitive control system, allowing people to adaptively apply varying levels of control across different task contexts based on learned environmental regularities.

Constraints on Generality

These findings were obtained from undergraduate student participants and are expected to generalize to healthy adults with normal color vision performing tasks that require cognitive control and attentional selection. The extent to which similar transfer occurs across other populations, stimulus dimensions, or task contexts remains to be established.

Declarations

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Availability of data and materials: All data has been made publicly available at https://osf.io/mc62z

Code availability: All analysis code has been made publicly available at https://osf.io/mc62z

Authors' contributions:

XM: Conceptualization, Software, Methodology, Investigation, Data curation, Project administration, Formal analysis, Validation, Visualization, Writing – original draft, Writing – review & editing

JMB: Conceptualization, Methodology, Writing – review & editing

RAA: Conceptualization, Methodology, Resources, Supervision, Writing – review & editing

Open Practices Statement

Trial-level data and analysis code for all experiments have been made publicly available at https://osf.io/mc62z, and none of the experiments was preregistered.

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