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Between-Task Transfer of Learned Control Settings: How Far Can It Go?

Merve Ileri Tayar
Washington University in St. Louis

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WASHINGTON UNIVERSITY IN ST. LOUIS

Department of Psychological and Brain Sciences

Between-Task Transfer of Learned Control Settings: How Far Can It Go?

by
Merve Ileri Tayar

A thesis presented to
Washington University in St. Louis
in partial fulfillment of the
requirements for the degree
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Merve Ileri Tayar

Washington University in St. Louis

December 2023

Dedicated to my beloved family.

ABSTRACT OF THE THESIS

Between-Task Transfer of Learned Control Settings: How Far Can It Go?

by

Merve Ileri Tayar

Master of Arts in Psychological and Brain Sciences

Washington University in St. Louis, 2023

Professor Julie Bugg, Chair

Learning-guided control refers to adjustments of cognitive control settings (i.e., relatively focused vs. relaxed) based on learned associations between predictive cues (e.g., stimulus features) and the likelihood of conflict. We investigated the transfer of learned control settings beyond the conditions under which they were learned to examine the flexibility and automaticity of these control settings. In Experiment 1, participants experienced an item-specific proportion congruence (ISPC) manipulation in a training phase in which target color in a Flanker task was biased (mostly congruent or mostly incongruent). Then, in a subsequent transfer phase, they performed a color-word Stroop task in which the same target colors were unbiased (i.e., 50% congruent). The same design was implemented in Experiment 2, but the training and transfer tasks were intermixed within the same block. Evidencing between-task transfer, participants in both experiments adjusted the control settings for the unbiased transfer items depending on the proportion congruence (PC) of the predictive cue (i.e., color), as learned in the training task. In Experiment 3, we investigated a farther version of between-task transfer by using different response sets and different relevant dimensions in the training (color-word Stroop) and transfer (produce Stroop) tasks. Despite the stronger boundary between the tasks, we again observed an ISPC effect with the transfer items; although in this case, the between-task transfer effect did not emerge until the second half of the experiment. The results provide converging evidence for the flexibility and automaticity of learning-guided control.

Introduction

Learned cognitive control settings refer to the mental templates that are developed through experience and used to guide how we allocate cognitive control resources. As we experience the world around us, we implicitly and automatically gather information about the regularities in it. These regularities show us how we should use and distribute our cognitive control resources to different information sources. For instance, imagine that you are playing a trivia game that requires you to respond to questions written in different colors. As you keep playing, you may (implicitly) learn that color predicts difficulty--questions written in red are generally harder than questions written in green. Learning this regularity may lead you to associate the color "red" with more difficult questions and "green" with less difficult questions. You may be more focused for the questions in red compared with the questions in green because they are associated with different levels of difficulty. This would be an example of learned control settings. After learning these control settings, only seeing the colors red and green may activate (retrieve) the control settings associated with the colors. The critical question we are interested in is: do these learned control settings transfer to a novel task? For example, imagine that now you are playing a different game involving red and green colors. In this game, however, the colors do not signal different levels of difficulty, and thus do not require different levels of cognitive control. Would you still automatically retrieve and execute previously learned control settings when you encounter the predictive cues (colors) in the new game? If so, this would indicate a between-task transfer of learned control settings.

Cognitive control refers to the ability to flexibly regulate the processing of information to align with the requirements (goals) of a given task by adjusting attention to prioritize task-relevant information while ignoring task-irrelevant information (Miller & Cohen, 2001). The Stroop task, which is commonly used to investigate cognitive control, is “the gold standard” of attentional measures (MacLeod, 1992). In a classic color-word Stroop task, participants are instructed to respond to the color of the word while ignoring the word itself. By comparing the reaction time and error rate between congruent (i.e., the color and the word match) and incongruent (i.e., the color and the word conflict) trials, researchers measure the interference (i.e., the difference between incongruent and congruent items) from the task-irrelevant information (word). However, participants can reduce this interference, thus the Stroop effect, by utilizing cognitive control to prioritize the task-relevant information (i.e., to-be-named dimension) while ignoring the task-irrelevant information (i.e., not-to-be-named dimension).

A type of cognitive control, learning-guided control, refers to the adjustment of cognitive control settings which are gained through learning the associations between stimulus features (predictive cues) and the likelihood of conflict (Abrahamse et al., 2016; Braem & Egner, 2018; Bugg & Egner, 2021; Chiu & Egner, 2019; Crump & Milliken, 2009; Egner, 2014). Prior experience shapes the distribution of cognitive resources to different stimuli or stimulus features to efficiently achieve the task goal and optimize cognitive performance. Compelling evidence demonstrating learning-guided control stems from studies employing the item-specific proportion congruence (ISPC) paradigm (Jacoby et al., 2003; for the confound-minimized variant used herein, see Bugg et al., 2011 and Bugg and Hutchison, 2013). In this paradigm, the probability of conflict is manipulated specific to items by presenting some items (e.g., colors blue and red) as mostly congruent (MC, i.e., presented with their matching word most of the trials) and other items (e.g., colors green and white) as mostly incongruent (MI, i.e., presented with their matching word most of the trials). Because MC and MI items are randomly intermixed in a 50% congruent list, it is not possible for participants to know whether the subsequent trial will have an MC or an MI color. Nevertheless, participants dynamically and reactively adjust cognitive control settings depending on the item type after seeing the stimulus. A more focused control setting is utilized for MI items (colors) while a more relaxed control setting is utilized for MC items (colors), resulting in a larger Stroop effect for the MC items compared with the MI items, referred to as the ISPC effect.

The ISPC effect can be explained by the episodic retrieval account (Brosowsky & Crump, 2018; Crump & Milliken, 2009). As Hommel (2004) suggested, participants create “event files” as they experience the trials within a task like Stroop. According to the episodic retrieval account, these event files include not only the stimulus but also the associated control settings as a network of bindings (see also Dignath et al., 2019; Egner, 2014). As participants experience MC and MI items, they create associations between stimulus features, the level of conflict, and the internal state (i.e., control settings). After creating these event files, being exposed to one component of the event file leads to retrieval of the other components. Therefore, after associating different control settings with stimulus features like color, being exposed to these features (predictive cues) in subsequent trials (e.g., seeing the color red again) flexibly triggers the retrieval and execution of previously learned control settings. This results in a smaller Stroop effect for the MI items since a focused control setting is retrieved and executed, and a larger Stroop effect for the MC items since a relaxed control setting is retrieved and executed.

In addition to this flexible nature, previous research also suggests that learning-guided item-specific control may be automatic (Bugg et al., 2011; Bugg & Dey, 2018; Chiu et al., 2017; Suh & Bugg, 2021). Automaticity of a cognitive process is generally manifested by being unintentional (i.e., occurring without explicit instruction or awareness as is the case for the ISPC effect, see Bejjani et al., 2020), stimulus-driven (i.e., reactively occurring for individual items rather than via top-down guidance), not being subject to voluntary control (see Entel et al., 2014 for evidence that participants could not voluntarily produce an ISPC effect), or being efficient (i.e., requiring minimal capacity and occurring with concurrent load; Moors & De Houwer, 2006; Suh & Bugg, 2021). Suh and Bugg (2021) tested the automaticity of item-specific control by examining the ISPC effect with differing concurrent working memory loads. They found converging evidence for the automaticity of item-specific control by observing the ISPC effect robustly across different levels (high and low) and types of working memory load (e.g., verbal load, spatial load, updating loads with an n-back task; also see Spinelli et al., 2020).

Transfer of Previously Learned Control Settings

Further evidence for the flexibility and automaticity of learning-guided item-specific control comes from the transfer of learned control settings beyond the conditions in which the settings were learned. Transfer refers to situations in which the mere presence of predictive cues flexibly and automatically triggers the retrieval and execution of learned control settings in novel conditions involving the predictive cue. Transfer can be conceptualized as falling on a continuum from near to far (or farther) transfer. Transfer may occur in a near sense in which the learned control settings transfer to novel stimuli within the same task, or in a far (farther) sense in which they transfer to a novel task involving novel stimuli.

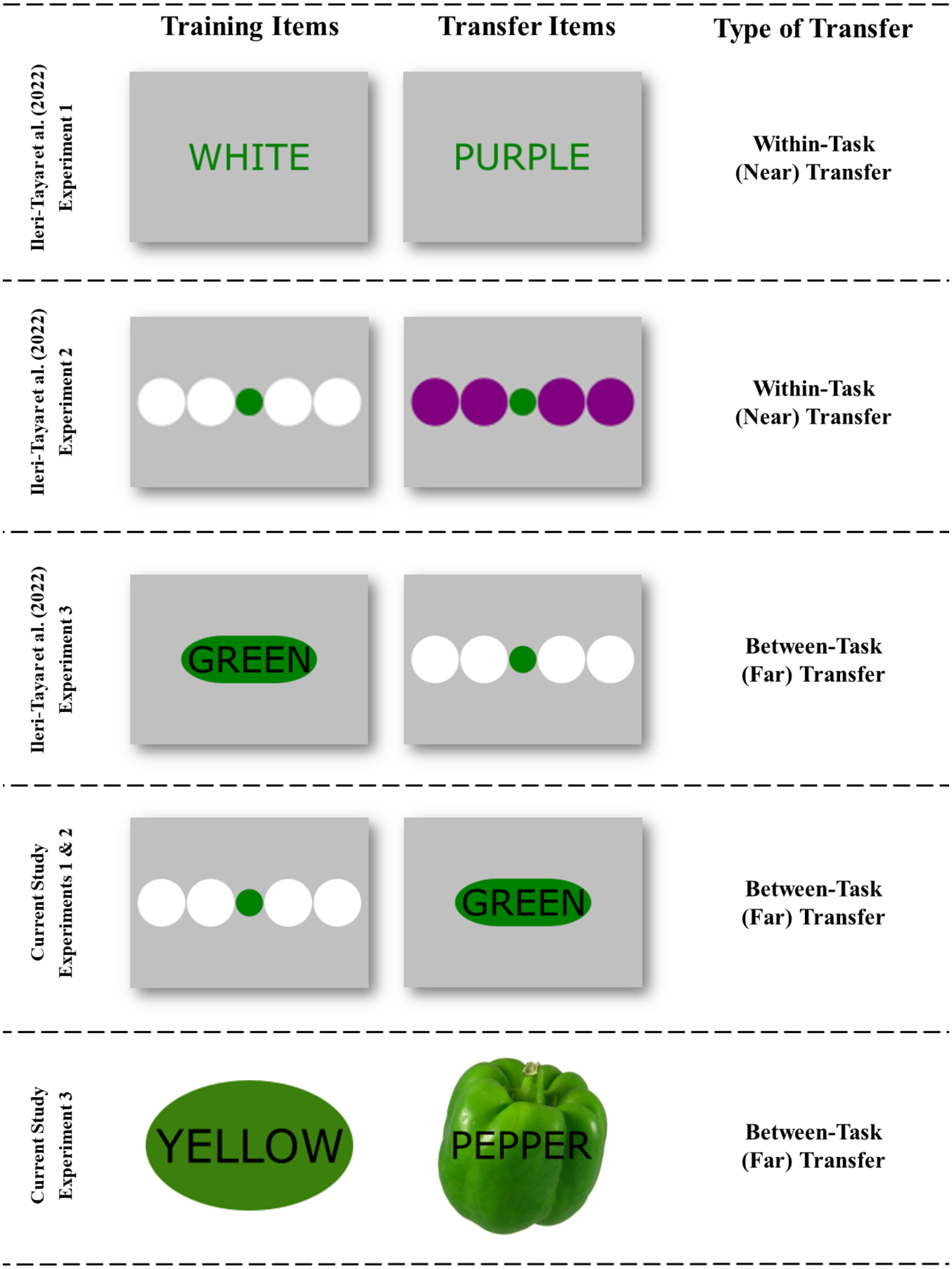
A few studies have examined the transfer of learned control settings in a near sense (i.e., within task-transfer; Bugg et al., 2011; Bugg & Hutchison, 2013; Bugg & Dey, 2018; Ileri-Tayar er al., 2022). Here we highlight the within-task transfer results from Bugg & Hutchison (2013) and Ileri-Tayar et al. (2022, Experiments 1 and 2) since they explored transfer of learned control settings based on a predictive cue that was color. In these experiments, participants learned the association between predictive cues (i.e., colors) and the likelihood of conflict in a training phase by experiencing an ISPC manipulation. In a following transfer phase, they encountered novel unbiased items (i.e., 50% congruent) involving the predictive cues that were intermixed with biased items within the same task as was used in the training phase (i.e., color-word Stroop task in Bugg & Hutchison and Experiment 1 of Ileri-Tayar et al., and color Flanker task in Experiment 2 of Ileri-Tayar et al.). In these experiments, participants transferred the previously learned control settings to novel unbiased items (i.e., faster responses to incongruent transfer stimuli comprising an MI color compared with an MC color), evidencing within-task transfer (please see Figure 1 for sample training items from Experiment 1 and 2 of Ileri-Tayar et al., 2022).

Between-task transfer represents a far form of transfer as compared to within-task transfer since not only the stimuli but also the overall task changes from the training to the transfer phase. However, only one prior study has examined the between-task transfer of learned item-specific control settings to date, to the best of our knowledge (Ileri-Tayar et al., 2022, Experiment 3). In that experiment, we aimed to investigate the transfer of learned control settings to an unbiased novel task (i.e., all items were 50% congruent) that involved the predictive cues participants associated with learned item-specific control settings in a different task. The experiment consisted of two training blocks and one transfer block. In the training blocks, participants performed a modified version of the color-word Stroop task (i.e., respond to the color of the shape while ignoring the word written in it) and learned the associations between predictive cues (i.e., colors) and the likelihood of conflict. In the transfer phase, they switched to a novel Flanker task (i.e., respond to the color of the center circle while ignoring the outer circles). The task and the stimuli were different across phases (please see Figure 1 for sample training items in

Experiment 3 of Ileri-Tayar et al., 2022). However, critically, the same colors were used in the training and transfer tasks. While the colors were MC or MI in the training task, they were all unbiased (i.e., 50% congruent) in the transfer task. The main question we were interested in was: can learned control settings transfer from a training task to a novel transfer task resulting in a significant ISPC effect with unbiased transfer items involving the predictive cue? Observing an ISPC effect with unbiased transfer items depending on the previous PC of the predictive cue (colors) would indicate the transfer of learned control settings. We found that being exposed to the predictive cues in a novel task, even though they were all unbiased in that task, flexibly and automatically triggered the retrieval and execution of previously learned control settings, resulting in a significant ISPC effect on the transfer task.

Figure 1.

Sample training and transfer items in Ileri-Tayar et al. (2022) and the current experiment.



Note. The first two rows of this figure (Experiments 1 and 2 in Ileri-Tayar et al.) demonstrate examples of within-task transfer. The predictive cue (the color green) repeats across training and transfer items within the same task. While transfer items are presented with the predictive cues from the training items, they are also presented with novel distractors (i.e., the word PURPLE and the outer circles in purple in these examples) as unbiased. The subsequent two rows (Experiment 3 in Ileri-Tayar et al. and Experiments 1 and 2 in the current study) demonstrate examples of between-task transfer. The predictive cue (the color green) repeats across training and transfer items across different tasks. While transfer items involve the predictive cues from the training items, the stimuli and the task are novel and unbiased. The stronger discrepancy across the items results in a further version of transfer compared with the previous two examples. The last row (Experiment 3 in the current study) illustrates an even farther version of between-task transfer. Similarly, the predictive cue (the color green) repeats across training and transfer items when the transfer task is novel and unbiased. Moreover, the response sets across the tasks are different and the predictive cue is the irrelevant dimension for the transfer items. This is the farthest version of the between-task transfer we investigated. Please see Method sections for the detailed description of design and stimuli.

Current Study

In the current study, we aimed to further investigate between-task transfer for two main reasons. First, we aimed to reproduce the between-task transfer effect and generalize it to different conditions (Experiments 1 and 2). In Ileri-Tayar et al. (2022), the effect size for between-task transfer was small relative to that observed for within-task transfer. This was expected because learned control settings are less likely to be retrieved when the current experience does not map as well onto prior experiences (i.e., different goals, different stimuli, and different conflict types). In addition, uniquely in the designs used to examine between-task transfer (separate training and transfer phases) it was expected that participants would eventually learn the regularities of the transfer task (all colors 50% congruent) while unlearning the training task regularities (some colors MC and others MI), which should weaken transfer. Even though it was not unexpected for between-task transfer to be associated with a small effect size, we aimed to reproduce the effect and generalize it to different conditions to test the reliability of between-task transfer. In Experiment 1, we used the same design as Ileri-Tayar et al. (2022, Experiment 3) but investigated between-task transfer in the reversed order (i.e., from Flanker to Stroop task). In Experiment 2, we used the same design as Experiment 1 by intermixing the training and transfer tasks rather than presenting them in different blocks. To preview our results, we again found evidence of between-task transfer in both experiments. Finally, in Experiment 3, we tested for farther between-task transfer by using a transfer task in which the predictive cue was the irrelevant dimension, meaning it was no longer the to-be-named stimulus dimension, and a different response set was employed.

Experiment 1

In Experiment 1, we aimed to reproduce the between-task transfer effect with a different task order (Flanker → Stroop) but otherwise using the same design in Ileri-Tayar et al. (2022, Experiment 3) who investigated transfer from Stroop to Flanker. First, it was important to reproduce the effect because it was novel and corresponded to a small effect size. Second, it was also theoretically important to see how different levels of conflict and learning, both for the training and transfer task, affect the between-task transfer. Our initial decision regarding the order of the tasks in Ileri-Tayar et al. (2022, Experiment 3) was based on the ISPC effects we observed with the Stroop and the Flanker tasks in the prior experiments of the same study. The ISPC effect was larger with the Stroop task (Ileri-Tayar et al., 2022, Experiment 1, M = 62 ms, η_p^2 = .51) compared with the Flanker task (Ileri-Tayar et al., 2022, Experiment 2, M = 14 ms, η_p^2 = .26). We interpreted this to mean that the learning and adjustment of control settings were stronger within the Stroop task compared to the Flanker task. We, therefore, decided to use the Stroop task in the training phase assuming the transfer of learned control settings would be more likely when there is stronger learning in the training task. However, the opposite is also plausible. It is possible that when the transfer task involves more conflict (i.e., yields bigger congruency effects as is the case for the Stroop task compared with the Flanker task), the need for control is greater thereby making the retrieval and execution of previously learned control settings more likely. Therefore, in the current Experiment 1, we swapped the order of the two tasks. Even though the learning of control settings was expected to be less strong in the training phase, the higher conflict in the transfer phase may still lead to the transfer of learned control settings.

During the training phase, participants learned the associations between predictive cues (i.e., colors) and the likelihood of conflict within the Flanker task. During the transfer phase, participants switched to the Stroop task involving the predictive cues (i.e., the same colors from the Flanker task) while they were all unbiased. If the learned control settings are flexibly and automatically transferred to a novel unbiased task when the predictive cues are encountered in the novel task, we should observe a significant ISPC effect with the transfer items depending on the previous PC of the predictive cues.

Method

This experiment, including the power analysis, experimental design, exclusionary criteria, and analytic plan, was fully pre-registered on Open Science Framework.

Participants. A priori power analysis was conducted with Cohen’s method using the G*Power software (Faul et al., 2007). For the smallest effect we were interested in (the ISPC effect with the transfer items), a sample size of 102 provides .95 power to detect an effect of .115 (η_p^2) with an alpha set at .05.[1] We collected data from 114 Washington University students who

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[1] We followed the same power analysis as Ileri-Tayar et al., 2022, and the effect size for the power analysis was selected from an unpublished study in our lab that found a significant ISPC effect with transfer items using a distinct but similar design (Colvett et al., in progress).

participated in the study to fulfill a credit as a partial requirement of Psychology courses.[2] All participants were native English speakers and reported that they have normal or corrected-to-normal vision and color vision. One participant was excluded from all analyses due to a high scratch trial rate (3-standard deviation above the mean of all participants), three due to a high error rate (3-standard deviation above the mean of all participants), and one for falling asleep during the experiment. Three participants were excluded due to unexpected problems that plausibly affected the validity of the measurement (i.e., two participants' experiments were interrupted by disruptive noises from an adjacent room during the session, and the lights turned off during one participant's session) resulting in 106 usable participants (25 females, 80 males, 1 other, mean age = 18.97, SD = 1.12). The study was approved by the Institutional Review Board at Washington University in St. Louis and all participants provided informed consent.

Design and stimuli. The design and stimuli closely followed Experiment 3 of Ileri-Tayar et al. (2022) with one exception. While the training task was the modified color-word Stroop (i.e., a color-word embedded in a colored shape) and the transfer task was the color Flanker task in Ileri-Tayar et al. (2022), the assignment of the tasks was reversed in the current experiment. The experiment consisted of three blocks, two training blocks with the Flanker task and a third transfer block using the Stroop task. For the first two training blocks, we used a 2 (Proportion Congruence: Mostly Congruent vs. Mostly Incongruent) x 2 (Trial Type: Congruent vs. Incongruent) within-subject design with the Flanker task. Five colored circles were presented in a row in blue, red, green, or white ink colors. The participants were required to respond to the color of the center circles while ignoring the color of the outer circles. The center (target) circle

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[2] The stopping rule (i.e., the maximum number of participants we can collect data from unless the total sample size drops below the target sample size) was indicated as 120 participants in the pre-registration.

matched the outer (distractor) circles in the congruent trials and mismatched in the incongruent trials (see Figure 2). As in Ileri Tayar et al. (2022), the target was smaller in size (i.e., ~1 cm in diameter) than the distractors (i.e., ~1.8 cm in diameter) and presented 100 ms later than the distractors. These differences between the target and distractor circles were intended to encourage the processing of the distractor dimension, requiring greater control to attend to the target circle. Items were divided into two sets creating MC items (i.e., 75% congruent; 36 times with the congruent word, 4 times with each incongruent word) and MI items (i.e., 25% congruent; 12 times with the congruent word, 12 times with each incongruent word) according to the relevant dimension (color). Whether a color was MC or MI was counterbalanced across participants.

For the transfer block, we used a 2 (Predictive Cue Proportion Congruence: Mostly Congruent vs. Mostly Incongruent) x 2 (Trial Type: Congruent vs. Incongruent) within-subject design. In a modified color-word Stroop task, a color-word (BLUE, RED, GREEN, or WHITE) in black ink was presented within a colored shape. Participants were required to name the color of the shape and ignore the printed word. Stimuli were either congruent (i.e., the color of the shape and the meaning of the word match) or incongruent (i.e., the color of the shape and the meaning of the word mismatch). As in the training task, the target (i.e., the colored shape) was presented 100 ms later than the distractor word. Critically, the same colors were used in the training and transfer tasks but the previously-MC or previously-MI colors from the training task were all 50% congruent in the transfer task. The stimulus frequencies are presented in Table 1.

Table 1

Frequency of Target-Distractor Pairings for Mostly Congruent (MC) and Mostly Incongruent (MI) Items in Experiment 1

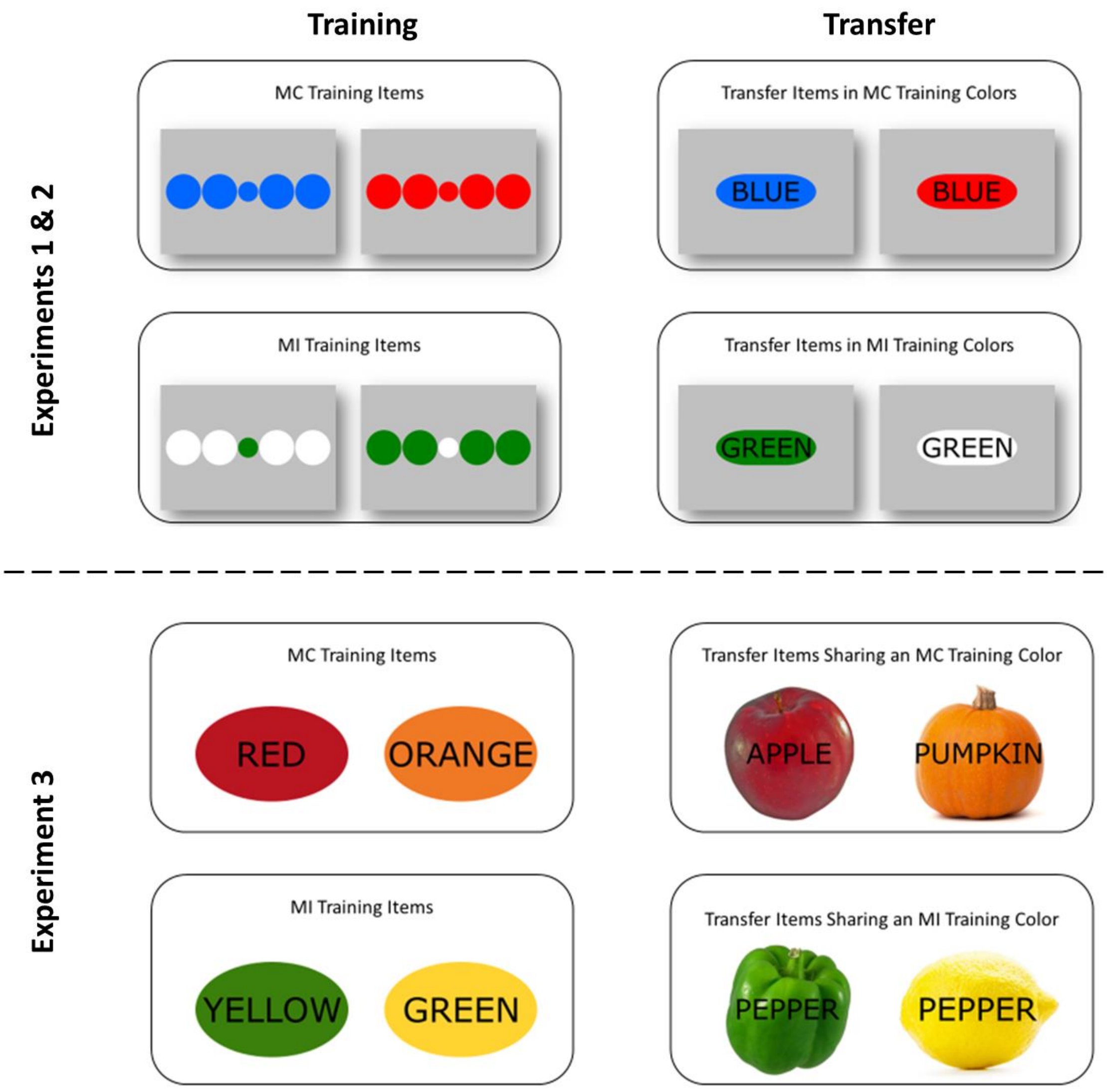
Block		Target			
	Distractor	Blue	Red	Green	White
Training	Blue	36	4	12	12
	Red	4	36	12	12
	Green	4	4	12	12
	White	4	4	12	12

Block		Target			
	Distractor	Blue	Red	Green	White
Transfer	Blue	24	8	8	8
	Red	8	24	8	8
	Green	8	8	24	8
	White	8	8	8	24

Note. Target refers to the color of the center circle in the Flanker task, and the color of the shape in the Stroop task. Distractor refers to the color of the flanker circles in the Flanker task, and to the meaning of the word in the Stroop task. In this table, the targets (colors) blue and red are MC, and green and white are MI; whether a color was MC or MI was counterbalanced across participants during the experiments.

Figure 2

Sample training (left column) and transfer (right column) items in Experiments 1, 2, and 3.



Note. In the training phase of Experiment 1, one set of target colors was presented as MC (i.e., 75% congruent) while the other set was MI (i.e., 25% congruent), counterbalanced across participants. In the transfer phase of Experiment 1, the same colors were presented as unbiased (i.e., 50% congruent) in a novel task in which color was also relevant (target) dimension. However, half of the colors were previously-MC and the other half were previously-MI. In Experiment 2, the same stimuli (and tasks) were used as in Experiment 1, but they were intermixed rather than presented in separate phases. Training items were presented as MC (i.e., 87.5 congruent) or MI (12.5% congruent), while all transfer items were 50% congruent. In Experiment 3, one set of target colors was presented as MC (i.e., 87.5% congruent) and the other set as MI (i.e., 12.5% congruent) in a modified color-word Stroop task in the training phase. Critically, these colors repeated in a novel transfer task (the produce Stroop task), but the color was not the relevant (i.e., to-be-named) dimension; rather, participants named the produce pictures. The transfer items were all 50% congruent, while they were presented with an MC or an MI predictive cue (i.e., color).[3]

Procedure. Each participant was tested individually. They were seated approximately 60 cm from the monitor and a standard microphone was used to record vocal responses. The experiment was programmed and presented on a 17-inch LCD monitor with the E-prime 2.0 software (Psychology Software Tools, Pittsburgh, PA). The participants were instructed to respond to the color of the target circle while ignoring the color of the distractor circles for the training block, and to respond to the color of the shape while ignoring the word in the transfer block. To make the transition between tasks as seamless as possible, participants were instructed that they will continue with the same task (i.e., a conflict task) with slightly different rules. All stimuli were presented on a gray background. For the training blocks, five colored circles in blue, red, green, or white ink were presented at the center of the screen, while the target was presented 100 ms after the distractors. The stimulus was presented on the screen until a voice response was detected. After the response, the stimulus disappeared, and the experimenter coded the vocal response of the participant using the keyboard. Trials in which the microphone was triggered by extraneous noise or imperceptible speech were coded as scratch trials. Then, a fixation cross (250 ms) and a blank screen (250 ms) were presented, followed by the next stimulus. Participants completed 22 trials before starting the training blocks to practice the task. The stimulus organization during the practice block mimicked the proportion congruence of the items during the main task. For the transfer block, a color-word (BLUE, RED, GREEN, WHITE; font: sans serif, font size: 30) was presented at the center of the screen embedded in a colored shape. The

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[3] The apple and pepper images were obtained from the Bank of Standardized Stimuli (BOSS) and are licensed under the Attribution-ShareAlike 3.0 Unported license (http://creativecommons.org/licenses/by-sa/3.0/). The pumpkin and lemon images were obtained from websites as free images (https://pixabay.com/ and https://freepik.com/).

target was presented 100 ms after the distractor and both remained on the screen until the participant’s response. Next, the experimenter coded the response, a 250 ms fixation cross was presented, and a 250 ms blank screen was presented.

Results

Trials slower than 1500 ms or faster than 200 ms were excluded from all analyses (eliminated 1.31% of total trials). Scratch trials were excluded from all analyses (eliminated 1.51% of total trials), and error trials (eliminated 1.24% of total trials) were excluded from the RT analyses. Mean RTs and error rates are presented in Table 2 for training items and in Table 3 for transfer items. To test our hypotheses, we examined performance in training and transfer items separately.

Table 2

Mean Reaction Times (RT) and Error Rates of Training Items in Experiment 1

PC	Trial Type	Mean RT (SE)	Mean Error Rate (SE)
MC	Incongruent	583 (6)	2.17 (0.24)
	Congruent	525 (6)	0.74 (0.08)
	Congruency Effect	*58*	*1.43*
MI	Incongruent	573 (6)	1.49 (0.13)
	Congruent	523 (6)	0.82 (0.14)
	Congruency Effect	*50*	*0.67*
	ISPC Effect	*8 ms**	*0.76%**

Note. Standard errors are presented in parentheses. Significant ISPC effects are shown with a star (*). PC = Proportion Congruence, MC = Mostly Congruent, MI = Mostly Incongruent.

Table 3

Mean Reaction Times (RT) and Error Rates of Transfer Items in Experiment 1

		All Blocks		First Half		Second Half	
PC	Trial Type	Mean RT (SE)	Mean Error Rate (SE)	Mean RT (SE)	Mean Error Rate (SE)	Mean RT (SE)	Mean Error Rate (SE)
MC	Incongruent	644 (11)	2.19 (0.33)	632 (12)	2.03 (0.40)	656 (11)	2.38 (0.47)
	Congruent	549 (9)	0.34 (0.10)	545 (9)	0.40 (0.16)	553 (9)	0.27 (0.13)
	Congruency Effect	*95*	*1.85*	*87*	*1.63*	*103*	*2.11*
MI	Incongruent	638 (11)	2.36 (0.33)	623 (11)	2.35 (0.45)	652 (11)	2.33 (0.40)
	Congruent	557 (9)	0.38 (0.12)	548 (9)	0.27 (0.13)	566 (10)	0.51 (0.22)
	Congruency Effect	*81*	*1.98*	*75*	*2.08*	*86*	*1.82*
	ISPC Effect	*14 ms**	*0.13%*	*12 ms**	*-0.45%*	*17 ms**	*0.29%*

Note. Standard errors are presented in parentheses. Significant ISPC effects are shown with a star (*). PC = Proportion Congruence, MC = Mostly Congruent, MI = Mostly Incongruent.

Reaction Time

Training Blocks (Flanker Task). A 2 (Proportion Congruence: Mostly Congruent vs. Mostly Incongruent) x 2 (Trial Type: Congruent vs. Incongruent) repeated-measures ANOVA was conducted on the training items (the first two blocks). Participants responded slower to the incongruent (M = 578 ms) compared to the congruent (M = 524 ms) trials, indicated by the main effect of trial type, $F(1, 105) = 629.29$, $p < .001$, $\eta_p^2 = 0.86$. The main effect of PC was also significant, $F(1, 105) = 8.88$, $p = .004$, $\eta_p^2 = 0.08$, indicating slower RTs for the MC items (M = 554 ms) compared to the MI items (M = 548 ms). Most importantly, the ISPC effect was found, as indicated by the significant PC x Trial Type interaction, $F(1, 105) = 12.27$, $p = .001$, η_p^2 =

0.10. The congruency effect was larger for the MC items (*M* = 58 ms) compared to the MI items (*M* = 50 ms).

Transfer Block (Stroop Task). As pre-registered and following Ileri-Tayar et al. (2022; see also Bugg & Hutchison, 2013), we excluded 44 participants from the transfer analysis that did not show a positive ISPC effect in the training phase and analyzed the remaining 62 participants. The rationale was that showing a positive ISPC effect in training (i.e., learning to adjust control settings based on the associations between predictive cues and the history of conflict) is necessary to be able to transfer learned control settings to a novel task. A 2 (Predictive Cue Proportion Congruence: Mostly Congruent vs. Mostly Incongruent) x 2 (Trial Type: Congruent vs. Incongruent) repeated-measures ANOVA was conducted on the transfer items (the last block) to test whether the participants transferred previously learned control settings to a novel unbiased task. The RT was slower for the incongruent (*M* = 641 ms) compared to the congruent (*M* = 553 ms) trials, as indicated by the main effect of trial type, $F(1, 61) = 280.31$, $p < .001$, $\eta_p^2 = 0.82$. The main effect of predictive cue PC was not significant, $F(1, 61) = 0.03$, $p = .861$, $\eta_p^2 = 0.00$. Critically, there was an ISPC effect, as indicated by a significant Predictive Cue PC x Trial Type interaction, $F(1, 61) = 12.50$, $p = .001$, $\eta_p^2 = 0.17$. The congruency effect was larger for the transfer items presented with MC predictive cues (*M* = 95 ms) compared to the items presented with MI predictive cues (*M* = 81 ms). This significant ISPC effect for transfer items demonstrates that participants who learned a difference between MC and MI colors in the Flanker task continued to use the predictive cue to adjust control settings in the Stroop task based on the previous PC the colors signaled. To examine whether the transfer effect changed across time, we analyzed the first and the second half of the transfer block separately, as pre-registered.

First Half of the Transfer Block. A 2 x 2 repeated-measures ANOVA revealed a main effect of trial type, *F*(1, 61) = 266.98, $p < .001$, $\eta_p^2 = 0.81$, showing slower RTs for the incongruent (*M* = 628 ms) compared to the congruent (*M* = 547 ms) trials. The main effect of predictive cue PC was not significant, *F*(1, 61) = 0.55, $p = .461$, $\eta_p^2 = 0.01$. Most importantly, the two-way interaction between predictive cue PC and trial type was significant, *F*(1, 61) = 5.80, $p = .019$, $\eta_p^2 = 0.09$, indicating an ISPC effect based on previous proportion congruency of the predictive cues. The congruency effect was larger for the transfer items presented with MC predictive cue (*M* = 87 ms) compared to the items presented with MI predictive cues (*M* = 75 ms).

Second Half of the Transfer Block. The same analyses were repeated for the second half of the transfer block. We observed a main effect of trial type, *F*(1, 61) = 220.59, $p < .001$, $\eta_p^2 = 0.78$, showing slower RTs for the incongruent (*M* = 654 ms) compared to the congruent (*M* = 560 ms) trials. The main effect of predictive cue PC was not significant, *F*(1, 61) = 1.16, $p = .285$, $\eta_p^2 = 0.02$. The ISPC effect based on the previous congruency of the predictive cue was significant as indicated by the two-way interaction between predictive cue PC and trial type, *F*(1, 61) = 8.61, $p = .005$, $\eta_p^2 = 0.12$. The congruency effect was larger for the transfer items presented with MC predictive cues (*M* = 103 ms) compared to the items presented with MI predictive cues (*M* = 86 ms).

Error Rates

Training Blocks (Flanker Task). A 2 (Proportion Congruence: Mostly Congruent vs. Mostly Incongruent) x 2 (Trial Type: Congruent vs. Incongruent) repeated-measures ANOVA was conducted on the training items. The error rate was lower for the congruent (*M* = 0.78%) compared to the incongruent (*M* = 1.83%) trials, as indicated by the main effect of trial type, *F*(1, 105) = 51.29, $p < .001$, $\eta_p^2 = 0.33$. The main effect of PC was not significant, *F*(1, 105) = 3.53, *p*

= .063, η_p^2 = 0.03. The PC x Trial Type interaction was significant, *F*(1, 105) = 6.89, *p* = .010, η_p^2 = 0.06, showing a significant ISPC effect. The congruency effect was larger for the MC items (*M* = 1.43%) compared to the MI items (*M* = 0.67%).

Transfer Block (Stroop Task). Following the RT analyses, we excluded the 44 participants that did not show a positive ISPC effect in RT in the training phase from the transfer analysis and analyzed the remaining 62 participants.[4] A 2 x 2 repeated-measures ANOVA demonstrated the main effect of trial type, *F*(1, 61) = 49.78, *p* < .001, η_p^2 = 0.45. The error rate was higher for the incongruent (*M* = 2.27%) compared to the congruent (*M* = 0.36%) trials. Neither the main effect of predictive cue PC, *F*(1, 61) = 0.25, *p* = .620, η_p^2 = 0.00, nor the Predictive Cue PC x Trial Type interaction, *F*(1, 61) = 0.11, *p* = .744, η_p^2 = 0.00, was significant.

Discussion

In Experiment 1, we observed between-task transfer from Flanker to Stroop task, reproducing the effect first reported by Ileri-Tayar et al. (2022) albeit with a different task order. The training items within the Flanker task yielded a significant ISPC effect (*M* = 8 ms, η_p^2 = 0.10), indicating that the association between predictive cues and the likelihood of conflict was learned. Being exposed to the predictive cues in the transfer phase led to retrieval and execution of learned control settings, resulting in a significant ISPC effect (*M* = 14 ms, η_p^2 = 0.17) with unbiased transfer items. Even though the likelihood of conflict was not different across transfer items, participants adopted a more focused control setting for transfer items presented with an MI predictive cue compared with an MC predictive cue. Interestingly, transfer was found both in the first half and the second half. That is, there was a significant ISPC effect both in the first half

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[4] Please note that we defined the exclusion criteria based on RT because the primary indicator of learning the association between items and history of conflict and adjusting control settings accordingly is RT.

(M = 12 ms, η_p^2 = 0.09) and the second half (M = 17 ms, η_p^2 = 0.12) of the transfer block. Reproducing between-task transfer with a different task order further demonstrated the flexibility and automaticity of learning-guided item-specific control.

As aforementioned, in Ileri-Tayar et al. (2022), we selected the more conflicting task (Stroop) as the training task to make the learning stronger in the training phase. In contrast, in the current experiment, the more conflicting Stroop task was used in the transfer phase. We thought it was possible that experiencing more conflict in the transfer phase may signal a greater need for control, thereby leading to retrieval of previously learned control settings even though the learning was less strong in the training task due to the use of a less conflicting task. The current experiment (Flanker → Stroop) yielded a numerically larger between-task transfer effect size (η_p^2 = 0.17) compared with the previous experiment (Stroop → Flanker) (η_p^2 = 0.04). It is consistent with the idea that the more need for control in the transfer phase (i.e., more conflicting task) may lead to a stronger between-task transfer even though the learning is less strong in the training phase (i.e., less conflicting task). Moreover, the effect was more stable as it existed in both blocks, rather than dissipating over time as in Ileri-Tayar et al. (2022).

Experiment 2

In Experiment 2, we again aimed to reproduce the between-task transfer effect. We used the same design in Experiment 1 where the Flanker task comprised biased (MC and MI) colors and therefore represented the training task, and the Stroop task was unbiased and therefore represented the transfer task. However, we used a novel procedure in which training and transfer trials (tasks) were intermixed within each block rather than blocked (i.e., in separate phases with transfer following training). Participants switched randomly between the Flanker and the Stroop tasks, performing whichever task was indicated by the stimulus that was presented on a given trial. This experiment was important for three main reasons. First, we again aimed to reproduce the between-task transfer effect under different conditions to further test the stability and generalizability. Second, we aimed to increase the effect size of the between-task transfer. We assumed that reducing the time interval between training and transfer items (i.e., presenting them in the same block instead of different blocks, as in the within-task transfer studies) would make the event files created for the training and transfer items more similar to each other. We also thought that the representations for the learned control settings (based on responding to the training items) would be more active while responding to transfer items, leading to a stronger between-task transfer effect. Third, because the random intermixing of items introduces a task-switching element into the experiment, we aimed to examine the influence of task-switching on between-task transfer exploratorily.

As in Experiment 1, we predicted there to be a significant ISPC effect with the training items, indicating learning of the associations between predictive cues (i.e., colors) and the likelihood of conflict. If the learned control settings are flexibly and automatically transferred to a novel unbiased task when the predictive cues are encountered, we should observe a significant ISPC effect with the transfer items depending on the PC of the predictive cues.

Method

This experiment, including the power analysis, experimental design, exclusionary criteria, and analytic plan, was fully pre-registered on Open Science Framework.

Participants. We followed the same a priori power analysis as Experiment 1 and aimed to collect data from at least 102 participants. We collected data from 115 Washington University students who participated in the study to fulfill a credit as a partial requirement of Psychology courses. All participants were native English speakers and reported that they have normal or corrected-to-normal vision and color vision. Three participants were excluded from all analyses due to a high scratch trial rate (3-standard deviation above the mean of all participants) and two due to a high error rate (3-standard deviation above the mean of all participants) resulting in 110 usable participants (88 females, 22 males, mean age = 19.21, SD = 1.20). The study was approved by the Institutional Review Board at Washington University in St. Louis and all participants provided informed consent.

Design and stimuli. The design and stimuli closely followed Experiment 1 such that the training task was Flanker and the transfer task was Stroop (see Figure 2), but there were three exceptions. First, instead of presenting training and transfer items (tasks) in separate blocks, they were randomly intermixed within a single block. Second, we used a more extreme PC manipulation for the training items to keep the PC 75% congruent for the MC colors and 25% congruent for the MI colors when combined with the transfer items since they were randomly presented within the same block. For the training items, we used a 2 (Proportion Congruence: Mostly Congruent vs. Mostly Incongruent) x 2 (Trial Type: Congruent vs. Incongruent) within-subject design. One set of colors (e.g., blue and red) was MC (i.e., 87.5% congruent; 84 times with the congruent word, 4 times with each incongruent word), and the other set (e.g., green and white) was MI (i.e., 12.5% congruent; 12 times with the congruent word, 28 times with each incongruent word), and this was counterbalanced across participants. For the transfer items, we used a 2 (Predictive Cue Proportion Congruence: Mostly Congruent vs. Mostly Incongruent) x 2 (Trial Type: Congruent vs. Incongruent) within-subject design. However, all four colors were presented as unbiased (i.e., 50% congruent) for transfer items, while two of them were MC-training colors and the other two were MI-training colors. The main experimental phase comprised three 192-trial blocks and a short break occurred between blocks. The stimulus frequencies are presented in Table 4.

The third change from Experiment 1 is that we included a 144-trial learning phase (block) prior to the main experimental phase. The learning phase followed the same design as the experimental phase. The goal of the learning phase before the experimental blocks was to allow participants to learn about the PCs of the predictive cues (colors) before the critical transfer trials. In the previous experiments, participants were able to learn about the PCs of the predictive cues, which is necessary for transferring learned control settings, before starting to respond to the transfer trials due to the blocked design, and we wanted to give the same learning opportunity to the participants in this experiment. To encourage participants to focus on the task, the learning phase was presented to participants as the first block of the experiment (i.e., it was not presented as a practice block). However, only the actual experimental blocks will be analyzed as pre-registered.

Table 4

Frequency of Target-Distractor Pairings for Mostly Congruent (MC) and Mostly Incongruent (MI) Items in Experiment 2

Items	Distractor	Target Blue	Red	Green	White
Training	Blue	84	4	28	28
	Red	4	84	28	28
	Green	4	4	12	28
	White	4	4	28	12

Items	Distractor	Target Blue	Red	Green	White
Transfer	Blue	24	8	8	8
	Red	8	24	8	8
	Green	8	8	24	8
	White	8	8	8	24

Note. Target refers to the color of the center circle in the Flanker task, and the color of the shape in the Stroop task. Distractor refers to the color of the flanker circles in the Flanker task, and the meaning of the word in the Stroop task. In this table, the targets (colors) blue and red are MC, and green and white are MI; whether a color was MC or MI was counterbalanced across participants during the experiments.

Procedure. The same procedure was followed as in Experiment 1, except that training and transfer items were randomly intermixed within the same blocks.

Results

Trials slower than 1500 ms or faster than 200 ms were excluded from all analyses (eliminated 1.65% of total trials). Scratch trials were excluded from all analyses (eliminated 1.90% of total trials), and error trials (eliminated 1.43% of total trials) were excluded from the RT analyses. Mean RTs and error rates are presented in Table 5. To test our hypotheses, we examined performance in training and transfer items separately.

Table 5

Mean Reaction Times (RT) and Error Rates of Training and Transfer Items in Experiment 2

Item Type	PC	Trial Type	All Blocks		First Half		Second Half	
			Mean RT (SE)	Mean Error Rate (SE)	Mean RT (SE)	Mean Error Rate (SE)	Mean RT (SE)	Mean Error Rate (SE)
Training Items	MC	Incongruent	583 (7)	1.70 (0.34)	584 (7)	1.79 (0.47)	582 (7)	1.92 (0.52)
		Congruent	530 (7)	1.08 (0.13)	533 (7)	1.55 (0.22)	528 (7)	1.93 (0.23)
		Congruency Effect	*53*	*0.62*	*51*	*0.24*	*54*	*-0.01*
	MI	Incongruent	572 (7)	1.72 (0.20)	574 (7)	1.91 (0.26)	569 (7)	2.67 (0.29)
		Congruent	528 (7)	1.04 (0.27)	530 (7)	1.34 (0.43)	527 (8)	2.19 (0.55)
		Congruency Effect	*44*	*0.68*	*44*	*0.57*	*42*	*0.48*
		ISPC Effect	*9 ms**	*-0.06%*	*7 ms*	*-0.33%*	*12 ms**	*-0.49%*
Transfer Items	MC	Incongruent	647 (11)	2.58 (0.34)	661 (9)	2.51 (0.46)	646 (9)	3.06 (0.49)
		Congruent	539 (8)	0.80 (0.19)	557 (7)	0.93 (0.25)	539 (6)	1.84 (0.37)
		Congruency Effect	*108*	*1.78*	*104*	*1.58*	*107*	*1.22*
	MI	Incongruent	637 (10)	2.42 (0.31)	655 (9)	2.63 (0.41)	636 (8)	3.09 (0.47)
		Congruent	541 (8)	0.88 (0.16)	559 (7)	1.27 (0.35)	539 (7)	2.23 (0.42)
		Congruency Effect	*96*	*1.54*	*96*	*1.36*	*97*	*0.86*
		ISPC Effect	*12 ms**	*0.24%*	*8 ms*	*0.22%*	*10 ms*	*0.36%*

Note. Standard errors are presented in parentheses. Significant ISPC effects are shown with a star (*). PC = Proportion Congruence, MC = Mostly Congruent, MI = Mostly Incongruent. Please note that the descriptives of the transfer items in the first and second half may belong to different participants since we only included the participants with positive ISPC effects with the training items to transfer analyses in each block.

Reaction Time

Training Items (Flanker Task). A 2 (Proportion Congruence: Mostly Congruent vs. Mostly Incongruent) x 2 (Trial Type: Congruent vs. Incongruent) repeated-measures ANOVA was conducted on the training items. The main effect of trial type was significant $F(1, 109) = 461.81$, $p < .001$, $\eta_p^2 = 0.81$, demonstrated by slower responses to the incongruent (M = 577 ms) compared to the congruent (M = 529 ms) trials. The main effect of PC was also significant, $F(1, 109) = 9.50$, $p = .003$, $\eta_p^2 = 0.08$, indicating slower RTs for the MC items (M = 556 ms) compared to the MI items (M = 550 ms). Importantly, the PC x Trial Type interaction was significant, $F(1, 109) = 8.61$, $p = .004$, $\eta_p^2 = 0.07$, indicating a significant ISPC effect. The congruency effect was larger for the MC items (M = 53 ms) compared to the MI items (M = 44 ms).

Transfer Items (Stroop Task). As pre-registered, we excluded 42 participants from the transfer analysis that did not show a positive ISPC effect with the training items and analyzed the remaining 68 participants.[5] A 2 (Predictive Cue Proportion Congruence: Mostly Congruent vs. Mostly Incongruent) x 2 (Trial Type: Congruent vs. Incongruent) repeated-measures ANOVA was conducted on the transfer items to test whether the control settings associated with the training items are transferred to unbiased transfer items in a different task. The participants responded slower to the incongruent (M = 642 ms) compared to the congruent (M = 540 ms) trials, demonstrated by the main effect of trial type, $F(1, 67) = 336.00$, $p < .001$, $\eta_p^2 = 0.83$. The main effect of Predictive Cue PC was not significant, $F(1, 67) = 1.15$, $p = .288$, $\eta_p^2 = 0.02$. Most critically, the Predictive Cue PC x Trial Type interaction was significant, $F(1, 67) = 6.71$, $p =$

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[5] One of the participants had a 0.45 ms ISPC effect with the training items which was rounded to 0 and not included in the transfer analyses. However, when we include this participant, the analyses yielded the same critical results (i.e., significant ISPC effect with the transfer items), $F(1, 68) = 7.24$, $p = 0.009$, $\eta_p^2 = .10$.

.012, η_p^2 = 0.09. The congruency effect was larger for the transfer items presented with MC predictive cues (*M* = 108 ms) compared to the items presented with MI predictive cues (*M* = 96 ms).

As a pre-registered analysis to examine whether training or transfer effects changed with more opportunities to learn about predictive cues (i.e., more time on task), we analyzed effects in the first half and second half of the experiment separately. Because the training and transfer items were intermixed within the same blocks, both the training and transfer items were analyzed for the first and the second half of the experiment.

First Half-Training Items. Participants responded slower to the incongruent (*M* = 579 ms) compared to the congruent (*M* = 531 ms) trials, indicated by the main effect of trial type, *F*(1, 109) = 376.50, *p* < .001, η_p^2 = 0.78. The main effect of PC was significant, *F*(1, 109) = 6.60, *p* = .012, η_p^2 = 0.06, indicating slower RTs for the MC items (*M* = 558 ms) compared to the MI items (*M* = 552 ms). Critically, the PC x Trial Type interaction was not significant, *F*(1, 109) = 2.70, *p* = .103, η_p^2 = 0.02. Even though the congruency effect was numerically larger for the MC items (*M* = 51 ms) compared to the MI items (*M* = 44 ms), the difference was not significant.

First Half-Transfer Items. We excluded 47 participants from the transfer analysis that did not show a positive ISPC effect with the training items in the first half of the experiment and analyzed the remaining 63 participants. We observed the main effect of trial type, *F*(1, 62) = 241.58, *p* < .001, η_p^2 = 0.80, showing the RT was slower for the incongruent (*M* = 658 ms) compared to congruent (*M* = 558 ms) trials. The main effect of predictive cue PC was not significant, *F*(1, 62) = 0.24, *p* = .626, η_p^2 = 0.00. Importantly, the two-way interaction between predictive cue PC and trial type was not significant, *F*(1, 62) = 1.64, *p* = .206, η_p^2 = 0.03. Even though there was a numerical difference, the congruency effect was not significantly different for the items presented with MC predictive cues (*M* = 104 ms) and MI predictive cues (*M* = 96 ms).

Second Half-Training Items. There was a main effect of trial type, *F*(1, 109) = 257.15, $p <$ .001, η_p^2 = 0.70. Participants responded slower to the incongruent (*M* = 575 ms) compared to the congruent (*M* = 527 ms) trials. The main effect of PC was also significant, *F*(1, 109) = 7.65, $p =$ .007, η_p^2 = 0.07, indicating slower RTs for the MC items (*M* = 555 ms) compared to the MI items (*M* = 548 ms). Most importantly, the PC x Trial Type interaction was significant, *F*(1, 109) = 7.65, $p = .007$, η_p^2 = 0.07. The congruency effect was larger for the MC items (*M* = 54 ms) compared to the MI items (*M* = 42 ms).

Second Half-Transfer Items. We excluded 48 participants from the transfer analysis that did not show a positive ISPC effect with the training items in the second half of the experiment and analyzed the remaining 62 participants. Responses were slower for incongruent (*M* = 641 ms) compared to congruent (*M* = 539 ms) trials, as indicated by the effect of trial type, *F*(1, 61) = 281.68, $p < .001$, η_p^2 = 0.82. The main effect of predictive cue PC was not significant, *F*(1, 61) = 1.35, $p = .250$, η_p^2 = 0.02. Critically, the two-way interaction between predictive cue PC and trial type was not significant, *F*(1, 61) = 2.73, $p = .104$, η_p^2 = 0.04, indicating similar congruency effects for the items presented with MC predictive cues (*M* = 107 ms) and MI predictive cues (*M* = 97 ms).

Error Rates

Training Items (Flanker Task). A 2 (Proportion Congruence: Mostly Congruent vs. Mostly Incongruent) x 2 (Trial Type: Congruent vs. Incongruent) repeated-measures ANOVA was conducted on the training items. The error rate was lower for the congruent (*M* = 1.06%) compared to the incongruent (*M* = 1.71%) trials, demonstrated by the main effect of trial type, *F*(1, 109) = 10.47, *p* = .002, η_p^2 = 0.09. Neither the main effect of PC, *F*(1, 109) = 0.00, *p* = .946, η_p^2 = 0.00, nor the PC x Trial Type interaction, *F*(1, 109) = 0.02, *p* = .878, η_p^2 = 0.00, was significant.

Transfer Items (Stroop Task). Following the RT analyses, we excluded the 42 participants that did not show a positive ISPC effect in RT with the training items from the transfer analysis and analyzed the remaining 68 participants. A 2 x 2 repeated-measures ANOVA demonstrated the main effect of trial type, *F*(1, 67) = 28.94, *p* < .001, η_p^2 = 0.30. The error rate was higher for the incongruent (*M* = 2.50%) compared to the congruent (*M* = 0.84%) trials. Neither the main effect of predictive cue PC, *F*(1, 67) = 0.03, *p* = .862, η_p^2 = 0.00, nor the Predictive Cue PC x Trial Type interaction, *F*(1, 67) = 0.36, *p* = .551, η_p^2 = 0.01, was significant.

Exploratory Task-Switching Analyses

Because participants responded to training and transfer items in the same block, they were randomly switching between the Flanker and Stroop tasks. We coded trials either as "task-repeat" (e.g., Flanker → Flanker; Stroop → Stroop) or "task-switch" (e.g., Stroop → Flanker; Flanker → Stroop) to test the influence of task-switching on the training and transfer effects. We excluded the first trial in each of the three blocks (since it could not be coded as a task-switch or task-repeat). Please note that we will only report the critical effects (i.e., effects including task repetition) to avoid redundancy.

Training Items. We ran a 2 (Proportion Congruence: Mostly Congruent vs. Mostly Incongruent) x 2 (Trial Type: Congruent vs. Incongruent) x 2 (Task Repetition: Task-Repeat vs. Task-Switch) repeated-measures ANOVA on the training items. The main effect of task repetition was not significant, *F*(1, 109) = 2.09, *p* = .151, η_p^2 = 0.02, indicating similar responses for the task-repeat (*M* = 552 ms) and the task-switch trials (*M* = 554 ms). The two-way interactions between PC and task repetition, *F*(1, 109) = 0.03, *p* = .858, η_p^2 = 0.00, and between trial type and task repetition, *F*(1, 109) = 1.28, *p* = .261, η_p^2 = 0.01, were not significant. However, the three-way interaction between PC, trial type, and task repetition was significant, *F*(1, 109) = 5.82, *p* = .018, η_p^2 = 0.05. While there was not an ISPC effect in task-switch trials (MC congruency effect = 50, MI congruency effect = 51), there was an ISPC effect in task-repeat trials (MC congruency effect = 53, MI congruency effect = 39).

Transfer Items. Following previous analyses, we excluded 42 participants from the transfer analysis that did not show a positive ISPC effect with the training items and analyzed the remaining 68 participants. A 2 (Predictive Cue Proportion Congruence: Mostly Congruent vs. Mostly Incongruent) x 2 (Trial Type: Congruent vs. Incongruent) x 2 (Task Repetition: Task-Repeat vs. Task-Switch) repeated-measures ANOVA was conducted on the transfer items to assess the influence of task repetition on transfer effect. The main effect of the task repetition was significant, *F*(1, 67) = 10.63, *p* = .002, η_p^2 = 0.14, indicating faster responses for the task-repeat trials (*M* = 585 ms) compared to the task-switch trials (*M* = 594 ms). The two-way interaction between trial type and task repetition was not significant (Stroop effect with task-switch trials = 105 ms, Stroop effect with task-repeat trials = 98 ms), *F*(1, 67) = 2.52, *p* = .117, η_p^2 = 0.01. Neither the two-way interaction between predictive cue PC and task repetition, *F*(1, 67) = 0.55, *p* = .462, η_p^2 = 0.01; nor the three-way interaction between trial type, task repetition, and predictive cue PC, *F*(1, 67) = 0.65, *p* = .423, η_p^2 = 0.01, was significant.

Discussion

In Experiment 2, reproducing the findings of Experiment 1, we observed between-task transfer from Flanker to Stroop task. The novel component was that we observed between-task transfer in an intermixed block design. A significant ISPC effect with the training items (M = 9 ms, η_p^2 = 0.07) indicated learning of the associations between predictive cues and the likelihood of conflict within the Flanker task. Moreover, being exposed to the predictive cues within the transfer items led to retrieval and execution of learned control settings, resulting in a significant ISPC effect (M = 12 ms, η_p^2 = 0.09) with unbiased transfer items within the Stroop task. Participants adopted a more focused control setting for transfer items presented with MI predictive cues compared with MC predictive cues, though having a completely equal likelihood of conflict for both item types. The results further supported the flexibility and automaticity of learning-guided item-specific control.

When we analyzed the first and second half of the experiment separately, the transfer effect was not significant, though numerically followed the same pattern as the overall analyses (first half, M = 8 ms, p = .206, η_p^2 = 0.03; second half, M = 10 ms, p = .104, η_p^2 = 0.04), possibly due to less power. Overall, when the training and transfer tasks were intermixed rather than blocked, the between-task transfer effect was consistent across blocks.

We expected to observe a larger between-task transfer effect in the present experiment compared with the blocked design of Experiment 1 because we assumed reducing the time interval between training and transfer tasks and keeping both task representations active within the same block would decrease the event boundaries and increase the between-task transfer. However, the effect size did not increase, and instead, it was numerically smaller (Experiment 1, η_p^2 = 0.17; Experiment 2, η_p^2 = 0.09). It may be due to the additional complexity task-switching brings in performing the task. Task-switching slowed down the responses in task-switch trials compared with task-repeat trials for the transfer items, though not with the training items. A factor contributing to this difference may be the higher level of conflict in the Stroop task.

Switching to a high-conflict task from a low-conflict task may be more challenging than switching to a low-conflict task from a high-conflict task. Even though it is not consistent with the asymmetrical switch cost pattern (greater switch-cost when switching to the less difficult task than when switching to the more difficult task; see Allport & Wylie, 2000) which is generally observed in task-switching paradigms, it may be due to the larger number of training items (2/3 of the total trials) compared with the transfer items in our study. It might have been harder to switch to the Stroop task from the Flanker task, rather than switching to the Flanker task from the Stroop task, due to more experience with the Flanker task. Moreover, task-switching influenced the ISPC effect with the training items. While there was not a significant ISPC effect in task-switch trials (i.e., Stroop → Flanker), there was a significant ISPC effect in task-repeat trials (i.e., Flanker → Flanker). However, it did not influence the ISPC effect with the transfer items. It signals that the between-task transfer was not specific to task-repeat or task-switch trials and did not solely result from the immediate experience of the training task (i.e., being exposed to biased predictive cues). Rather, it signals a more long-term stable cognitive process.

Experiment 3

After observing a robust and reliable between-task transfer effect in Experiments 1 and 2, we aimed to test for farther between-task transfer in Experiment 3 to provide insights into a possible boundary condition for between-task transfer. The training and transfer items in Experiments 1 and 2, even though they differed in several ways (e.g., task, stimuli, conflict type), shared a critical factor: the response set. Because the predictive cue (i.e., color) was the relevant (i.e., to-be-named) dimension in both the Stroop and the Flanker tasks, participants kept responding with "blue", "red", "green", and "white" when they transitioned from the training to transfer tasks. Using the same response set (and therefore sharing the same relevant dimension) may create a connection between the tasks and make the between-task transfer more likely. Conversely, having different response sets and not sharing the relevant dimension across tasks may create a stronger boundary between the training and transfer tasks that may eliminate between-task transfer. According to Wühr et al. (2015), sharing the relevant dimension of the stimulus is a necessary condition for the transfer of a distinct but related, list-wide proportion congruence (LWPC, i.e., manipulating PC across blocks rather than items) effect. They observed that the transfer effect disappeared when the relevant dimension was not shared across tasks. It is also sensible considering that participants are required to attend to the relevant dimension to be able to achieve the task goal. Because they necessarily attend to the relevant dimension, it is more likely to observe transfer when the relevant dimension carries the transferred information.

It is unknown whether sharing the relevant dimension is a necessary condition for the transfer of item-specific control settings. We tested this possibility in Experiment 3 by using a transfer task in which the predictive cues were present but irrelevant (i.e., not the to-be-named dimension of the stimulus) such that different response sets were used across tasks. The transfer task we used was a novel version of the picture-word Stroop task in which produce pictures served as the relevant dimension (referred to hereafter as “produce Stroop task”). The training task was the modified version of the color-word Stroop task (i.e., the transfer task in Experiments 1 and 2) with novel colors (i.e., red, orange, green, yellow) to match the colors of the produce pictures. For the transfer task, we presented produce pictures with words embedded in them corresponding to these pictures (i.e., apple [in red color], pumpkin [in orange color], pepper [in green color], lemon [in yellow color], see Figure 2). Because these pictures involved the training colors, participants were exposed to the predictive cues in the transfer task; however, they responded to the identity of the picture (e.g., “apple”) rather than its color. Moreover, the items in the transfer task (i.e., both colors and produce pictures) were all unbiased. This allowed us to test if having different response sets and not sharing the relevant dimension across tasks create a strong boundary eliminating the between-task transfer. Briefly put, we aimed to test it as a possible boundary condition of between-task transfer in Experiment 3.

Another aim was to further examine the effects of task-switching on the ISPC effect with the training and transfer trials as in Experiment 2. Because the participants used the same response set in Experiment 2, some may argue that there was not a clear task-set switch for the participants, and instead, they always adopted a “name the color” task-set. Therefore, changing the relevant dimension/switching between response sets in Experiment 3 would allow a test of a farther version of between-task transfer. If having the same response set and sharing the relevant dimension across tasks is a necessary condition for the transfer of previously learned control settings, then we should not observe a significant ISPC effect with the transfer items, indicating a boundary condition for between-task transfer. However, if the mere presence of the predictive cue is sufficient for the retrieval and execution of learned control settings, then we should observe a significant ISPC effect with the transfer items, even when the response set and relevant dimension are not shared across tasks. Because Experiment 3 is expected to create the strongest boundary across tasks due to the aforementioned changes, the between-task transfer in Experiment 3 would be the farthest version of between-task transfer of item-specific learned control settings to date, providing further and converging evidence for the flexibility and automaticity of these processes.

Method

This experiment, including the power analysis, experimental design, exclusionary criteria, and analytic plan, was fully pre-registered on Open Science Framework.

Participants. Following the same a priori power analysis as Experiments 1 and 2, we aimed to collect data from at least 102 participants. We collected data from 107 Washington University students who participated in the study to fulfill a credit as a partial requirement of Psychology courses. All participants were native English speakers and reported that they have normal or corrected-to-normal vision and color vision. Two participants were excluded from all analyses due to a high scratch trial rate (3-standard deviation above the mean of all participants) and two due to a high error rate (3-standard deviation above the mean of all participants) resulting in 103 usable participants (65 females, 38 males, mean age = 19.40, SD = 1.18). The study was approved by the Institutional Review Board at Washington University in St. Louis and all participants provided informed consent.

Design and stimuli. The design closely followed Experiment 2 but with different stimuli. We used a modified color-word Stroop task as the training task and a produce Stroop task (i.e., a picture-word Stroop task using produce pictures) as the transfer task. In the color-word Stroop task, a color-word (RED, ORANGE, GREEN, or YELLOW) was embedded in a colored shape creating a congruent or an incongruent trial. Participants were instructed to respond to the color (red, orange, green, or yellow) of the shape while ignoring the word. In addition to using a different set of colors than Experiments 1 and 2, we also used a larger shape to make the appearance more similar to transfer items (please see Figure 2). In the produce Stroop task, a produce word (APPLE, PUMPKIN, PEPPER, or LEMON) was embedded in the produce pictures creating congruent (e.g., the word APPLE embedded in an apple picture) or incongruent (e.g., the word APPLE embedded in a pumpkin picture) trials. Participants were instructed to name the produce picture (apple, pumpkin, pepper, or lemon) while ignoring the word. Critically, the colors used in the training task (color-word Stroop) also appeared in the transfer task (produce Stroop, e.g., the apple was red, pumpkin was orange, pepper was green, and lemon was yellow), but the color was the irrelevant (i.e., not-to-be-named) dimension for the transfer items, unlike in Experiments 1 and 2.

For the training items, we used a 2 (Proportion Congruence: Mostly Congruent vs. Mostly Incongruent) x 2 (Trial Type: Congruent vs. Incongruent) within-subject design. The same PC manipulation was applied as in Experiment 2 (i.e., 87.5% congruent for the MC and 12.5% congruent for the MI items). For the transfer items, we used a 2 (Predictive Cue Proportion Congruence: Mostly Congruent vs. Mostly Incongruent) x 2 (Trial Type: Congruent vs. Incongruent) within-subject design.[6] The stimulus frequencies are presented in Table 6.

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[6] Note that we used "Predictive Cue PC" term to be consistent with the previous experiments. However, predictive cue is the irrelevant (i.e., not-to-be-named) dimension for the transfer items while it is the relevant (i.e., to-be-named) dimension for the training items, contrary to previous experiments where the predictive cue was the relevant dimension for both training and transfer items.

Table 6

Frequency of Target-Distractor Pairings for Mostly Congruent (MC) and Mostly Incongruent (MI) Items in Experiment 3

Items		Target			
	Distractor	Red	Orange	Green	Yellow
Training	Red	84	4	28	28
	Orange	4	84	28	28
	Green	4	4	12	28
	Yellow	4	4	28	12

Items		Target			
	Distractor	Apple	Pumpkin	Pepper	Lemon
Transfer	Apple	24	8	8	8
	Pumpkin	8	24	8	8
	Pepper	8	8	24	8
	Lemon	8	8	8	24

Note. Target refers to the color of the shape in the color-word Stroop task, and the picture in the produce Stroop task. Distractor refers to the meaning of the word both in the color-word Stroop and the produce Stroop tasks. In this table, the targets (colors) red and orange are MC, and green and yellow are MI; whether a color was MC or MI was counterbalanced across participants during the experiments.

Procedure. The procedure was identical to Experiment 2, except that participants were instructed to name the color of the shape in the color-word Stroop task and name the picture in the produce Stroop task. As in Experiment 2, training and transfer items were randomly intermixed in a block. We again used a 144-trial learning phase prior to the main experimental phase. The main experiment phase comprised three 192-trial blocks and a short break occurred between blocks.

Results

Trials slower than 1500 ms or faster than 200 ms were excluded from all analyses (eliminated 2.44% of total trials). Scratch trials were excluded from all analyses (eliminated 2.89% of total trials), and error trials (eliminated 2.62% of total trials) were excluded from the

RT analyses. Mean RTs and error rates are presented in Table 7. To test our hypotheses, we examined performance in training and transfer items separately.

Table 7

Mean Reaction Times (RT) and Error Rates of Training and Transfer Items in Experiment 3

			All Blocks		First Half		Second Half	
Item Type	PC	Trial Type	Mean RT (SE)	Mean Error Rate (SE)	Mean RT (SE)	Mean Error Rate (SE)	Mean RT (SE)	Mean Error Rate (SE)
Training Items	MC	Incongruent	780 (10)	2.89 (0.35)	784 (10)	2.77 (0.52)	780 (10)	3.12 (0.50)
		Congruent	644 (7)	0.91 (0.08)	650 (7)	0.81 (0.10)	638 (7)	1.01 (0.12)
		Congruency Effect	*136*	*1.98*	*134*	*1.96*	*142*	*2.11*
	MI	Incongruent	721 (8)	1.83 (0.15)	725 (8)	1.61 (0.17)	718 (8)	2.06 (0.19)
		Congruent	643 (7)	0.80 (0.18)	648 (8)	0.58 (0.22)	638 (8)	0.94 (0.28)
		Congruency Effect	*78*	*1.03*	*77*	*1.03*	*80*	*1.12*
		ISPC Effect	*58 ms**	*0.95%**	*57 ms**	*0.93%*	*62 ms**	*0.99%*
Transfer Items	MC	Incongruent	765 (8)	6.76 (0.54)	772 (9)	6.00 (0.70)	762 (9)	7.55 (0.68)
		Congruent	657 (7)	3.31 (0.34)	664 (8)	3.80 (0.51)	648 (8)	4.07 (0.53)
		Congruency Effect	*108*	*3.45*	*108*	*2.2*	*114*	*3.48*
	MI	Incongruent	767 (8)	6.69 (0.48)	782 (11)	6.73 (0.64)	753 (8)	8.50 (0.72)
		Congruent	656 (7)	3.36 (0.38)	663 (9)	2.60 (0.35)	654 (8)	4.76 (0.62)
		Congruency Effect	*111*	*3.33*	*119*	*4.13*	*99*	*3.74*
		ISPC Effect	*-3 ms*	*0.12%*	*-11 ms*	*-1.93%*	*15 ms**	*-0.26%*

Note. Standard errors are presented in parentheses. Significant ISPC effects are shown with a star (*). PC = Proportion Congruence, MC = Mostly Congruent, MI = Mostly Incongruent. Please note that the descriptives of the transfer items in the first and second half may belong to different participants since we only included the participants with positive ISPC effects with the training items to transfer analyses in each block.

Reaction Time

Training Items (Color-Word Stroop Task). A 2 (Proportion Congruence: Mostly Congruent vs. Mostly Incongruent) x 2 (Trial Type: Congruent vs. Incongruent) repeated-measures ANOVA was conducted on the training items. The main effect of trial type was significant, $F(1, 102) = 591.94$, $p < .001$, $\eta_p^2 = 0.85$. Participants responded slower to the incongruent ($M = 751$ ms) compared to the congruent ($M = 643$ ms) trials. The main effect of PC was also significant, $F(1, 102) = 97.92$, $p < .001$, $\eta_p^2 = 0.49$, indicating slower RTs for the MC items ($M = 712$ ms) compared to the MI items ($M = 682$ ms). Importantly, the PC x Trial Type interaction was significant, $F(1, 102) = 129.76$, $p < .001$, $\eta_p^2 = 0.56$, showing a significant ISPC effect. The congruency effect was larger for the MC items ($M = 136$ ms) compared to the MI items ($M = 78$ ms).

Transfer Items (Produce Stroop Task). As pre-registered, we excluded 13 participants from the transfer analysis that did not show a positive ISPC effect with the training items and analyzed the remaining 91 participants. A 2 (Predictive Cue Proportion Congruence: Mostly Congruent vs. Mostly Incongruent) x 2 (Trial Type: Congruent vs. Incongruent) repeated-measures ANOVA was conducted on the transfer items to examine whether the participants continue to modulate control settings based on the PC of the predictive cue even though the it is the irrelevant dimension for the transfer items since the color is not-to-be-named dimension of the stimulus. The RT was slower for the incongruent ($M = 766$ ms) compared to the congruent ($M = 657$ ms) trials, demonstrated by the main effect of trial type, $F(1, 90) = 521.35$, $p < .001$, $\eta_p^2 = 0.85$. The main effect of predictive cue PC was not significant, $F(1, 90) = 0.01$, $p = .910$, $\eta_p^2 = 0.00$.

Critically, the Predictive Cue PC x Trial Type interaction was not significant, $F(1, 90) = 0.19$, $p = .667$, $\eta_p^2 = 0.00$. The congruency effect was similar for the transfer items presented with MC predictive cues (M = 108 ms) and the items presented with MI predictive cues (M = 111 ms). As pre-registered, to assess whether training or transfer effects changed with more opportunities to learn about predictive cues, we analyzed effects in the first half and second half of the experiment separately. Because the training and transfer items were intermixed, both the training and transfer items were analyzed for the first and the second half of the experiment.

First Half-Training Items. Participants responded slower to the incongruent (M = 755 ms) compared to the congruent (M = 649 ms) trials, indicated by the main effect of trial type, $F(1, 102) = 414.36$, $p < .001$, $\eta_p^2 = 0.80$. The main effect of PC was also significant, $F(1, 102) = 73.95$, $p < .001$, $\eta_p^2 = 0.42$, indicating slower RTs for the MC items (M = 717 ms) compared to the MI items (M = 687 ms). Moreover, the PC x Trial Type interaction was significant, $F(1, 102) = 62.74$, $p < .001$, $\eta_p^2 = 0.38$. The congruency effect was larger for the MC items (M = 134 ms) compared to the MI items (M = 77 ms).

First Half-Transfer Items. We excluded 23 participants from the transfer analysis that did not show a positive ISPC effect with the training items in the first half of the experiment and analyzed the remaining 79 participants. We observed the main effect of trial type, $F(1, 78) = 414.33$, $p < .001$, $\eta_p^2 = 0.84$, showing that the RT was slower for the incongruent (M = 777 ms) compared to congruent (M = 663 ms) trials. The main effect of predictive cue PC was not significant, $F(1, 78) = 0.65$, $p = .422$, $\eta_p^2 = 0.01$. Critically, the two-way interaction between predictive cue PC and trial type was not significant, $F(1, 78) = 2.67$, $p = .106$, $\eta_p^2 = 0.03$. The congruency effect was similar for the transfer items presented with MC predictive cues (M = 108 ms) compared to the items presented with MI predictive cues (M = 119 ms).

Second Half-Training Items. Participants responded slower to the incongruent (*M* = 749 ms) compared to the congruent (*M* = 638 ms) trials, indicated by the main effect of trial type, *F*(1, 102) = 514.56, *p* < .001, η_p^2 = 0.83. The main effect of PC was also significant, *F*(1, 102) = 59.82, *p* < .001, η_p^2 = 0.37, indicating slower RTs for the MC items (*M* = 709 ms) compared to the MI items (*M* = 678 ms). Importantly, the PC x Trial Type interaction was significant, *F*(1, 102) = 78.78, *p* < .001, η_p^2 = 0.44. The congruency effect was larger for the MC items (*M* = 142 ms) compared to the MI items (*M* = 80 ms).

Second Half-Transfer Items. We excluded 14 participants from the transfer analysis that did not show a positive ISPC effect with the training items in the second half of the experiment and analyzed the remaining 88 participants. A 2 x 2 repeated-measures ANOVA showed the main effect of trial type, *F*(1, 87) = 420.78, *p* < .001, η_p^2 = 0.83, indicating slower RTs for the incongruent (*M* = 758 ms) compared to congruent (*M* = 651 ms) trials. The main effect of predictive cue PC was not significant, *F*(1, 87) = 0.15, *p* = .704, η_p^2 = 0.00. Most critically, the two-way interaction between predictive cue PC and trial type was significant, *F*(1, 87) = 6.40, *p* = .013, η_p^2 = 0.07, indicating an ISPC effect based on the PC of the predictive cue even though the predictive cue (i.e., color) is the irrelevant dimension for the transfer items. The congruency effect was larger for the items presented with MC predictive cues (*M* = 114 ms) compared to the items presented with MI predictive cues (*M* = 99 ms) with the training items.

Error Rates

Training Blocks (Color-Word Stroop task). A 2 (Proportion Congruence: Mostly Congruent vs. Mostly Incongruent) x 2 (Trial Type: Congruent vs. Incongruent) repeated-measures ANOVA was conducted on the training items. The error rate was lower for the congruent (*M* = 0.85%) compared to the incongruent (*M* = 2.36%) trials, demonstrated by the main effect of trial type, $F(1, 102) = 52.04$, $p < .001$, $\eta_p^2 = 0.34$. The main effect of PC was significant, $F(1, 102) = 10.76$, $p = .001$, $\eta_p^2 = 0.10$. The error rate was higher for the MC ($M = 1.90\%$) compared to the MI ($M = 1.31\%$) items. The PC x Trial Type interaction was also significant, $F(1, 102) = 6.23$, $p = .014$, $\eta_p^2 = 0.06$. The congruency effect was larger for the MC items ($M = 1.98\%$) compared to the MI items ($M = 1.03\%$).

Transfer Block (Produce Stroop task). Following the RT analyses, we excluded 13 participants that did not show a positive ISPC effect with RT with the training items from the transfer analysis and analyzed the remaining 91 participants. We ran a 2 (Predictive Cue Proportion Congruence: Mostly Congruent vs. Mostly Incongruent) x 2 (Trial Type: Congruent vs. Incongruent) repeated-measures ANOVA. Error rate was higher for incongruent ($M = 6.73\%$) compared to congruent ($M = 3.34\%$) trials, as indicated by the effect of trial type, $F(1, 90) = 57.95$, $p < .001$, $\eta_p^2 = 0.39$. Neither the main effect of predictive cue PC, $F(1, 90) = 0.00$, $p = .985$, $\eta_p^2 = 0.00$, nor the Predictive Cue PC x Trial Type interaction, $F(1, 90) = 0.02$, $p = .876$, $\eta_p^2 = 0.00$, was significant.[7]

Exploratory Task-Switching Analyses

Because participants responded to training and transfer items in the same block, they were randomly switching between the color-word Stroop and produce Stroop tasks. We again coded trials either as “task-repeat” or “task-switch” to test the influence of task-switching on the training and transfer items. We excluded the first trial in each of the three blocks (since it could not be coded as a task-switch or task-repeat). Please note that we will only report the critical effects (i.e., effects including task repetition) to avoid redundancy.

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[7] The two-way interaction was not significant in the first, $F(1, 78) = 3.52$, $p = .064$, $\eta_p^2 = .04$; and the second half of the experiment $F(1, 87) < 1$.

Training Items. We conducted a 2 (Proportion Congruence: Mostly Congruent vs. Mostly Incongruent) x 2 (Trial Type: Congruent vs. Incongruent) x 2 (Task Repetition: Task-Repeat vs. Task-Switch) repeated-measures ANOVA on the training items. The main effect of task repetition was significant, *F*(1, 102) =113.09, *p* < .001, η_p^2 = 0.53, indicating faster responses for the task-repeat trials (*M* = 686 ms) compared to the task-switch trials (*M* = 719 ms), indicating a significant task switch cost. The two-way interaction between trial type and task repetition was not significant, *F*(1, 102) = 3.50, *p* = .064, = 0.03. Neither the two-way interaction between predictive cue PC and task repetition, *F*(1, 102) = 0.08, *p* = .772, η_p^2 = 0.00; nor the three-way interaction between trial type, task repetition, and predictive cue PC, *F*(1, 102) = 0.27, *p* = .601, η_p^2 = 0.00, was significant.

Transfer Items. Following previous analyses, we excluded 13 participants from the transfer analysis that did not show a positive ISPC effect with the training items and analyzed the remaining 91 participants. A 2 (Predictive Cue Proportion: Mostly Congruent vs. Mostly Incongruent) x 2 (Trial Type: Congruent vs. Incongruent) x 2 (Task Repetition: Task-Repeat vs. Task-Switch) repeated-measures ANOVA was conducted on the transfer items to assess the influence of task repetition on transfer effect. The main effect of the task repetition was significant, *F*(1, 90) = 117.47, *p* < .001, η_p^2 = 0.57, indicating faster responses for the task-repeat trials (*M* = 693 ms) compared to the task-switch trials (*M* = 720 ms). The two-way interaction between predictive cue PC and task repetition, *F*(1, 90) = 0.13, *p* = .716, η_p^2 = 0.00; the two-way interaction between trial type and task repetition, *F*(1, 90) = 0.58, *p* = 450, = 0.01; and the three-way interaction, *F*(1, 90) = 1.50, *p* = .224, η_p^2 = 0.02, were not significant.

Discussion

Reproducing and extending the results of Experiments 1 and 2, we observed between-task transfer from the color-word Stroop task to the produce Stroop task, even though the response set was not shared across tasks and the predictive cue was not the relevant dimension in the transfer task. This result demonstrated the farthest version of the between-task transfer of learned control settings to date. We believe it is the farthest between-task transfer demonstrated to date because it survived the strongest boundary conditions. In addition to the differences across tasks as in Experiments 1 and 2, the response set also was different across tasks leading to not sharing the relevant dimension. There was a clear switch cost both for the training and transfer items, whereas there was a switch cost only for the transfer items in Experiment 2. Observing the between-task transfer in these conditions provided strong support for the flexibility and automaticity of item-specific control settings.

Following the previous results, participants learned the associations between predictive cues and the likelihood of conflict, indicated by a significant ISPC effect with the training items within the Stroop task (M = 58 ms, η_p^2 = 0.56). The overall ISPC effect with the transfer items was not significant with the produce Stroop task. However, the between-task transfer was significant in the second half of the experiment (M = 15 ms, η_p^2 = 0.07). The automatic retrieval and execution of previously learned control settings when being exposed to the predictive cues within the novel unbiased transfer items became more pronounced with more experience. Please note that the training and transfer items were intermixed in this experiment rather than blocked. Thus, the transfer effect was not expected to dissipate over time since the training items were presented both in the first and the second half of the experiment. The reason for observing the between-task transfer in the second half, but not the first half may be that participants needed more experience with training and transfer items in the same block to be able to create the connection (i.e., predictive cue overlap) given larger boundaries across tasks. We would not have been surprised if there was no between-task transfer in either half of the experiment given that different response sets and relevant dimensions were used creating a strong boundary across tasks (Wühr et al., 2015). However, as participants experience the training and transfer items within the same block longer, the between-task transfer occurred in the second half by overcoming the boundaries. Participants adopted a more focused control setting for transfer items presented with MI predictive cues compared with MC predictive cues, even though having them as irrelevant (i.e., not-to-be-named) dimensions of the stimuli.

We ran task-switching analyses to explore the influence of the intermixed design, following Experiment 2. Task-switching slowed down the responses in task-switch trials compared with task-repeat trials both for the training and transfer items, indicating a switch cost. It was expected specifically considering that training and transfer tasks have different response sets and different relevant dimensions, creating a challenging mental switch for the task representation. However, task-switching did not influence the ISPC effect with the training or the transfer items.

General Discussion

In the current study, we aimed to further investigate the between-task transfer of learning-guided item-specific control. In all experiments, after learning the associations between predictive cues and the likelihood of conflict, being exposed to the predictive cues in a novel unbiased task led participants to retrieve and execute the control settings tied to these cues. Retrieval and execution of learned control settings beyond the conditions where they were learned point to the flexibility and automaticity of learning-guided item-specific control mechanisms. Collectively, these results reproduced and extended the results of Ileri-Tayar et al. (2022) by observing between-task transfer in a novel transfer direction (i.e., the assignment of training and transfer tasks, Experiment 1), in an intermixed design (Experiment 2), and in an intermixed design with a transfer task not sharing the response set and relevant dimension with the training task (Experiment 3). These findings provided converging evidence for the reliability and robustness of the effect and further supported the episodic retrieval account of item-specific control. Moreover, the results further challenged the contingency learning account of item-specific control (i.e., using the irrelevant dimension of the stimulus to predict responses on high contingency trials, see Schmidt & Besner, 2008), since simple contingency learning is not able to explain the transfer of the ISPC effect to a novel task.

Please note that there are two critical factors that may determine the between-task transfer: learning of control settings and retrieval and execution of control settings. To be able to observe between-task transfer, first, participants should learn the associations between predictive cues and the likelihood of conflict to adjust control settings accordingly. Second, being exposed to the predictive cues in a novel unbiased task should lead to flexible and automatic retrieval and execution of control settings even though these control settings do not map well onto the current experience. The design factors were chosen to facilitate these two components (e.g., more extreme PCs of training items and intermixed design in Experiments 2 and 3, broad feature similarity across training and transfer items, etc.), and the results will be evaluated considering them in the following paragraphs.

Examining the change of between-task transfer over time is an important step to comprehend its nature. In Experiment 1, interestingly, the transfer effect did not disappear, as we would expect, in the second half of the transfer block. Due to the blocked design of the experiments, participants did not experience any biased items in the transfer block. It was expected that as participants experience the novel unbiased items, existing episodes (event files) bound to the predictive cues would be updated according to the current environment. As participants unlearn the previous associations and learn the current ones, the control settings associated with predictive cues would become an “intermediate” control setting (Diede & Bugg, 2017) for all colors rather than a focused one for the MI and a relaxed one for the MC colors. This was the case in Experiment 3 of Ileri-Tayar et al. (2022). While there was a significant ISPC effect in the first half of the transfer block (*M* = 9 ms), it was not found in the second half (*M* = 2 ms). Unexpectedly, the transfer effect was found in both halves of the transfer block in the current Experiment 1 (first half, *M* = 12 ms, η_p^2 = 0.09; second half, *M* = 17 ms, η_p^2 = 0.12). However, a closer look at the source of the ISPC effects in these sections reveals differences in control adjustment across blocks. In the first half, there was a significant difference between the incongruent transfer items presented with the MC (*M* = 632 ms) and the MI colors (*M* = 623 ms), *t*(61) = 1.72, *p* = .045, *d* = .22, indicating more focused control settings for the MI-incongruent items compared with MC-incongruent items. However, there was no difference between the congruent transfer items presented with the MC (*M* = 545 ms) and the MI (*M* = 548 ms) colors, *t*(61) = -0.51, *p* = .306, *d* = .07. In the second half of the transfer block, however, the source of the effect switched. While, there was no difference between the incongruent transfer items presented with the MC (*M* = 656 ms) and the MI (*M* = 652 ms) colors, *t*(61) = 0.71, *p* = .240, *d* = .09; there was a significant difference between the congruent transfer items presented with the MC (*M* = 553 ms) and the MI (*M* = 566 ms) colors, *t*(61) = -2.88, *p* = .003, *d* = .37. Therefore, participants did not continue to adopt a more focused control setting for the MI items, but instead they adopted a more relaxed control setting for the MC items in the second half. It signals that they updated the event files, specifically for the MI items, as they experience a novel environment where adopting a focused control setting was demanding and no longer efficient. However, they transferred relaxed control settings to the novel stimuli including the MC predictive cue, possibly due to less cognitive effort required (Kool et al., 2010).

In Experiment 2, our expectations regarding the change of the between-task transfer effect over time were different than Experiment 1 due to the intermixed design. Because participants kept experiencing both the training and transfer items within the same block, we assumed the representations of predictive cues and the likelihood of conflict associations (event files) would be active throughout the experiment. Thus, we did not expect to observe a dissipated transfer effect over time. It was even plausible to observe an increased transfer effect over time due to stronger associations created for training items and a possible binding between training and transfer items. Even though the between-task transfer effect was not statistically significant when the blocks were analyzed separately, possibly due to less power, there was numerically no difference between the ISPC effects in the first (M = 8 ms, η_p^2 = 0.03) and the second half of the experiment (M = 10 ms, η_p^2 = 0.04), as expected. Please also note that there was no significant ISPC effect with the training items in the first half of the experiment when analyzed separately (M = 7 ms, p = .103), which also signals power issues in block analyses.

The pattern of between-task transfer between halves in Experiment 3 differed from both Experiments 1 and 2. While it was not significant in the first half of the experiment, it was significant in the second half. Some may wonder if it was because it was harder to learn the item-specific associations with the training items, specifically in the first half, since different response sets across the items magnified the switch cost. Even though there was a significant switch cost with the training items (i.e., slower responses to task-switch trials [*M* = 719 ms] compared with task-repeat trials [*M* = 686 ms]), participants were still able to learn the associations between predictive cues and the likelihood of conflict demonstrated by a significant ISPC effect in the first half of the experiment with training items (*M* = 57 ms, η_p^2 = 0.38). Thus, we can eliminate the possibility that the lack of transfer in the first half was due to the difficulty of learning the control settings, which signals the primary reason may be related to the retrieval of learned control settings. Being exposed to the predictive cues on transfer trials in the first half did not lead to automatic retrieval and execution of learned control settings associated with these cues. However, that retrieval and execution occurred in the second half, signaling that more time was potentially needed to overcome the boundaries across tasks and create the event files binding the predictive cues in the transfer items with the learned control settings in the training items. It is not surprising that creating the connection between training and transfer items took time specifically considering that the response sets were different across tasks and the predictive cue was the irrelevant dimension in the transfer task. Since participants were not necessarily attending to the colors when responding to the transfer items, there was not an immediate connection between the transfer items and the control settings associated with predictive cues. However, as participants continue to experience the training and transfer items within the same block, the boundaries across tasks were eliminated and a representation binding the transfer items with learned control settings was created.

The between-task transfer also informs us about the nature of the learning-guided item-specific control processes. In Experiments 1 and 2, the types of conflict were different across tasks. While there was a semantic conflict in the Stroop task, a spatial conflict was more pronounced in the Flanker task, which requires participants to utilize different type of control mechanisms for the tasks if the control is conflict-specific. For instance, a “word filtering” mechanism could be used to avoid conflict in the Stroop task, while a “spatial filtering” mechanism would be proper in the Flanker task. Thus, “conflict-specific” control mechanisms would not be able to explain the between-task transfer in Experiments 1 and 2 due to different types of conflict. Instead, a more abstract control mechanism such as adjusting the weight of the relevant and irrelevant dimensions during response selection would be more appropriate to explain the between-task transfer. Experiment 3 involves a slightly different scenario. Because participants are required to ignore the word dimension in both tasks, the conflict type is more similar across tasks (semantic conflict) even though the stimuli are different. So, it is possible a word-filtering mechanism could be transferred from the training to the transfer task. With the current data, we are not able to dissociate if participants use a word-filtering mechanism or a more abstract control mechanism in Experiment 3. It also opens the question if participants would use a simpler conflict-specific control mechanism when they are able to apply it to all items in a list as compared with a list involving different types of conflict, thus requiring a more abstract control mechanism. Another question it brings is whether we would observe between-task transfer when the conflict types differ across tasks in addition to the existing differences (i.e., different response sets, not sharing the relevant dimension, etc.). The possibility that the conflict type created a connection between training and transfer tasks in Experiment 3, enabling the transfer of control which would not be otherwise possible, should be further investigated.

Boundary Conditions of Between-Task Transfer

As we consider the between-task transfer, it is important to examine what factors are critical in enabling this transfer to occur and what factors could prevent such transfer from happening. Therefore, an important question to ask is: What factors facilitate between-task transfer, and what are the boundary conditions that may hinder it?

Throughout all experiments, even though the stimuli were unique to the task, we made an effort to maintain “broad feature similarity” between the predictive cues across tasks to support transfer (Cochrane & Pratt, 2022b, p. 2). Following Ileri-Tayar et al. (2022), in Experiments 1 and 2, we used a modified version of the color-word Stroop task (i.e., words embedded within colored shapes) and an atypical version of the Flanker task (i.e., a target colored-circle with distractor colored-circles). We specifically chose a round shape for the Stroop task and a circle for the Flanker task, in order to keep the appearance of the predictive cues similar. Our reasoning for this was based on the likelihood of observing between-task transfer, which we believed would have been lower if we used the classic version of the color-word Stroop task (i.e., words in different inks). In Experiment 3, we maintained broad feature similarity by selecting produce items with round shapes and making the shape in the Stroop task more circular. We also made an effort to match the color of the picture (please note that the colors in the pictures were not homogeneous since they are real-life pictures of produces) and the predictive cue in the Stroop task. Supporting our reasoning and findings, prior research investigating the transfer of different types of control also showed that shared stimulus features (Bustamante et al., 2021) facilitate transfer (also see Bejjani et al., 2018 for linking the stimuli through associative learning, and see Weidler & Bugg, 2016 for linking the stimuli through spatial locations). Additionally, we used the same response modality (i.e., vocal response) in all tasks, as it appears that different response modalities (e.g., vocal response in the training task and manual response in the transfer task) may create a strong boundary across conditions, eliminating between-task transfer (Colvett et al., 2022).

In Experiment 3, we tested the hypothesis that different response sets combined with not sharing the relevant dimension would create a boundary condition, thereby eliminating transfer between tasks. We assumed that the responses stored in event files would be a key element for binding the training and transfer items. Also, prior studies had shown that overlapping responses were critical even for within-task transfer (Bugg & Dey, 2018) which is a less extreme version of transfer. Moreover, because the predictive cues were not the relevant dimension for the transfer items, participants were not necessarily attending to them, which decreases the possibility of the retrieval of control settings bound to predictive cues. We can argue that different response sets and not sharing the relevant dimension indeed created a boundary for the first half of the experiment, and participants likely formed different representations for the tasks. However, it was not the case for the second half. As they continue to encounter the tasks within the same block, the event files were likely merged forming a single representation, resulting in the transfer effect. In addition to the factors facilitating transfer that were explained in the prior paragraph (i.e., broad feature similarity and shared response modality), some other design factors may have been influential in producing transfer. For example, we presented a learning phase prior to the actual experiment to help participants learn about the predictive cues. Additionally, the intermixed design likely facilitated connections between the tasks as participants continued to experience them within the same block. Overall, we can conclude that while different response sets and not sharing the relevant dimension may create a boundary for transfer in the initial stages of performance, continued exposure and the use of design factors such as a learning phase and intermixed task design may help facilitate transfer between tasks. Moreover, overcoming these boundaries provided further support for the flexibility and automaticity of the retrieval and execution of item-specific control settings due to the mere existence of the predictive cues.

Between-Task Transfer of Other Types of Control

The current study combined with our previous study (Ileri-Tayar et al., 2022) represents the first demonstration of the between-task transfer of item-specific control. However, other studies investigated the between-task transfer of different types of control and have generally faced challenges in observing such transfer. In the subsequent paragraphs, we would like to discuss these studies and explore possible differences from our study.

Most of the prior research on between-task transfer focused on the congruency sequence effect (i.e., CSE, reduced congruency effect in the trials following incongruent trials compared with following congruent trials), testing whether the CSE would occur when the previous trial is a different task than the current trial. However, it has been challenging to observe between-task transfer with CSE (Egner, 2008). One important difference between CSE and ISPC is that while control adjustments primarily depend on the immediately preceding trial in CSE, they depend on learning the associations between predictive cues and the likelihood of conflict across many trials in ISPC. Because the ISPC effect represents long-term cumulative learning, it may be more automatically and flexibly retrieved on transfer trials. Another possibility is that because each transfer trial is a task-switch in those experiments investigating between-task transfer with CSE, task-switching may be interfering with the transfer. However, observing between-task transfer with our intermixed design in Experiments 2 and 3 challenges this explanation. Also, a critical difference between our study and most of the prior studies on CSE is that the predictive cue repeats across training and transfer items, creating a connection between them in our study. This repetition may trigger the retrieval and execution of event files containing control settings. In contrast, there is generally no immediate connection across training and transfer items in most of the CSE studies (please see Wühr et al., 2015 for an example where the relevant dimension was shared across tasks and a between-task transfer was observed with CSE).

Another line of research on between-task transfer of control concerns the transfer of cognitive flexibility (Siqi-Liu & Egner, 2020, 2022; Wen et al., 2022). Siqi-Liu and Egner (2020, 2022) investigated the between-task transfer of cognitive flexibility (i.e., adjustments of switch-readiness depending on the overall proportion of switching within a list) in a cued-task switching paradigm. They embedded an unbiased transfer task (i.e., presented equally often as task-switch and task-repeat trials) within biased lists with a biased task (i.e., presented as a high-switch task or a low-switch task). They observed that cognitive flexibility was task-specific and it did not generalize to a broader (list-wide) context as indicated by performance on the unbiased task. Between-task transfer of cognitive flexibility was not observed even when there was a stimulus-set overlap across tasks (Siqi-Liu & Egner, 2022, Experiment 3). Therefore, the task set was a boundary for the retrieval and execution of learned cognitive flexibility (switch-readiness) settings. Contrarily, Wen et al. (2021) observed between-task transfer of cognitive flexibility in a probabilistic version of Wisconsin Card Sorting task. Siqi-Liu & Egner (2022) reasoned that because task-switching was voluntary in Wen et al., it may lead to the transfer of cognitive flexibility. However, our results, considering that the task-switching was not voluntary, suggest that there are likely other factors that determined whether the between-task transfer of control is observed or not. It is not surprising to observe different results for these studies and our study since the underlying cognitive processes are different. Similar to the comparison we made with CSE studies, one important difference is that the predictive cues signaling different control settings did not overlap across tasks creating a connection between them in cognitive flexibility studies. It is possible that the item-specific nature of control processes in the current study made it easier to observe between-task transfer due to the repetition of the critical item feature (i.e., predictive cue). This suggests that the nature of the control processes being transferred, as well as the design features of the tasks being used, are important factors to determine between-task transfer.

Limitations and Future Directions

One limitation of the current study is that we used the positive ISPC effect as an indication of learning in the training task and only included these "learners" in the transfer analyses on the assumption that learning of predictive cues (i.e., learning that certain colors are MC and others MI) is necessary for transferring the learned control settings (Bugg & Hutchison, 2013; Ileri-Tayar et al., 2022). Even though it was a pre-registered decision, there are some limitations. When we define the learners based on positive ISPC effects, it means that a participant with +1 ISPC effect is considered a learner while a participant with 0 ISPC effect is not considered a non-learner. We need a better way to categorize learners and non-learners, as it is not easy to create a single threshold when the ISPC effect varies across tasks and experiments. Another limitation was that analyzing the first and second half of the experiment (or the transfer block for Experiment 1) separately necessarily led to a smaller number of data points in these analyses, thus reducing the power.

Moving forward, there are several promising directions for future research based on the findings and implications of this study. The interplay between learning of control settings and the retrieval and execution of control settings is not well understood. Even though we aimed for strong learning of training items, it is also possible that a stronger learning of training may lead to a stronger dissociation between training and transfer items. As participants learn the associations between predictive cues and the likelihood of conflict for the training items, they may become better at distinguishing between the training and transfer items due to the different levels of conflict associated with them. To put it differently, as the bond between predictive cues and associated control settings becomes stronger (i.e., stronger learning), the PC differences between training and transfer items may become more apparent. This increased differentiation could create a stronger boundary between the tasks. Understanding the relative weights of learning of control settings and the retrieval and execution of control settings on between-task transfer would be an important step to explore the boundary conditions of transfer. Whether between-task transfer occurs may vary depending on the design choices focusing on these two factors and future research is needed to explore their effect on between-task transfer.

Conclusion

In this study, we aimed to further investigate between-task transfer and test a possible boundary condition, not sharing the response set and the relevant dimension across tasks. Across three experiments, participants retrieved and executed the previously learned control settings associated with predictive cues, when they were exposed to the predictive cues in a novel unbiased task. The learned control settings were transferred to a novel unbiased task even when the predictive cue was the irrelevant dimension, and the response sets were distinct. These findings provided strong support for the flexibility and automaticity of learning-guided item-specific control settings such that encountering the predictive cues in a novel unbiased task led to the retrieval of the event file including these predictive cues and the execution of associated control settings.

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