Journal of Experimental Psychology:
Human Perception and Performance
2013, Vol. 39, No. 2, 433–449

0096-1523/13/$12.00 DOI: 10.1037/a0029145

Converging Evidence for Control of Color–Word Stroop Interference at the Item Level

Julie M. Bugg
Washington University in St. Louis

Keith A. Hutchison
Montana State University

Prior studies have shown that cognitive control is implemented at the list and context levels in the color–word Stroop task. At first blush, the finding that Stroop interference is reduced for mostly incongruent items as compared with mostly congruent items (i.e., the item-specific proportion congruence [ISPC] effect) appears to provide evidence for yet a third level of control, which modulates word reading at the item level. However, evidence to date favors the view that ISPC effects reflect the rapid prediction of high-contingency responses and not item-specific control. In Experiment 1, we first show that an ISPC effect is obtained when the relevant dimension (i.e., color) signals proportion congruency, a problematic pattern for theories based on differential response contingencies. In Experiment 2, we replicate and extend this pattern by showing that item-specific control settings transfer to new stimuli, ruling out alternative frequency-based accounts. In Experiment 3, we revert to the traditional design in which the irrelevant dimension (i.e., word) signals proportion congruency. Evidence for item-specific control, including transfer of the ISPC effect to new stimuli, is apparent when 4-item sets are employed but not when 2-item sets are employed. We attribute this pattern to the absence of high-contingency responses on incongruent trials in the 4-item set. These novel findings provide converging evidence for reactive *control* of color–word Stroop interference at the item level, reveal theoretically important factors that modulate reliance on item-specific control versus contingency learning, and suggest an update to the item-specific control account (Bugg, Jacoby, & Chanani, 2011).

Keywords: cognitive control, stroop interference, proportion-congruence effects, contingency learning

Cognitive control involves, in part, the use of goal representations to bias attention toward relevant information and against irrelevant information. Its importance is often illustrated in situations that require a nondominant or nonhabitual response. As an example, cognitive control is needed for a football coach to attend to the position and movement of the players off of the ball and override the dominant tendency to attend to the movement of the ball itself. In the laboratory, the color–word Stroop task (Stroop, 1935) is frequently used to examine the ability to overcome habitual response tendencies, and instead respond on the basis of a stimulus that is not routinely attended. In this task, participants name the ink color in which color words are presented (e.g., saying "red" in response to the word GREEN in red ink). The tendency for humans to read words interferes with color naming, and is manifested in prolonged response times and increased error rates on incongruent (GREEN in red) as compared with congruent (GREEN in green) trials (i.e., the Stroop effect).

This article was published Online First July 30, 2012.

Julie M. Bugg, Department of Psychology, Washington University in St. Louis; Keith A. Hutchison, Department of Psychology, Montana State University.

We are grateful to Erica Dayan, Jacqueline Greb, Kelsey Link, and David Tardif for assistance with data collection, and two anonymous reviewers for drawing our attention to the correlation account and suggesting the content-based error analyses. Portions of these data were presented at the 52nd Annual Meeting of the Psychonomic Society, Seattle, WA.

Correspondence concerning this article should be addressed to Julie M. Bugg, Campus Box 1125, One Brookings Drive, Washington University in St. Louis, St. Louis, MO 63130. E-mail: jbugg@artsci.wustl.edu

A prominent question in the literature concerns the mechanisms humans use to control attention in situations where interference is present. According to the *dual-mechanisms-of-control account* (Braver, Gray, & Burgess, 2007), interference in the Stroop task may be resolved via *proactive control*, a global preparatory mechanism aimed at minimizing interference, or *reactive control*, a local mechanism that is implemented on an as-needed basis, when stimuli are encountered that evoke interference. Evidence is emerging in support of the dual-mechanisms-of-control account, and more generally, the view that control can be implemented at multiple levels in the Stroop task (cf. Bugg, Jacoby, & Toth, 2008). We briefly review this evidence, then present three experiments designed to address a current gap in the literature, which is the absence of evidence for item-specific control of color–word Stroop interference.

Evidence for Multiple Levels of Control

At least since the initial reports of a *list-wide proportion congruence effect* (i.e., less interference in mostly incongruent than in mostly congruent lists), it has been assumed that control of Stroop interference can occur at the list level (e.g., Botvinick, Braver, Barch, Carter, & Cohen, 2001; Lindsay & Jacoby, 1994; Logan, Zbrodoff, & Williamson, 1984; Lowe & Mitterer, 1982; but see Blais & Bunge, 2010; Bugg et al., 2008). List-level control refers to the biasing of attention (toward or away from the processing of the irrelevant word) in a uniform or global fashion for all trials within a list (i.e., block) even prior to stimulus onset, and thus is considered a proactive mechanism. Recently, it has been demonstrated that the list-wide proportion congruence effect does in fact reflect list-level control (Bugg & Chanani, 2011; Bugg, McDaniel, Scullin, & Braver, 2011; Hutchison, 2011; but see Bugg et al., 2008). For instance, it has been shown that interference is reduced for items that appear in mostly incongruent as compared with mostly congruent lists, even when the congruency of the items themselves is equated across lists (Bugg & Chanani; Hutchison). In addition, Bugg, McDaniel, et al. (2011) showed that neutral trial (e.g., WINDOW in green ink) response times were faster in mostly incongruent than in mostly congruent lists. Finally, it has been shown that performance of a secondary task that required attending to the Stroop words was impaired in mostly incongruent (relative to mostly congruent) lists, consistent with the view that attention is globally biased away from word processing when interference is frequent (Bugg, McDaniel, et al., 2011).

In addition to revealing proactive control, proportion congruence manipulations have also been used to provide evidence for reactive control of color–word Stroop interference. One line of evidence stems from paradigms that manipulate context-specific proportion congruence (Crump, Gong, & Milliken, 2006). In these paradigms, a contextual cue (e.g., location, shape, or color) accompanies each Stroop stimulus, with cue values (e.g., upper vs. lower location) corresponding to proportion congruency levels (mostly congruent or mostly incongruent). Stimuli are usually congruent when they appear in one location, and are usually incongruent when they appear in the other location. Stroop interference is reduced for stimuli that occur in the mostly incongruent as compared with the mostly congruent location, a finding Crump et al. referred to as the *context-specific proportion congruence* (CSPC) effect. The CSPC effect suggests that control can be implemented at a level that is more local than the list level. In particular, the CSPC effect suggests that within a single list of trials, one control setting is applied to all stimuli that occur in the context of one cue (i.e., the upper location) and another control setting is applied to the *same* stimuli when accompanied by a different contextual cue (i.e., the lower location). Because participants do not know which cue will accompany the stimulus on each trial, context-level control must reflect reactive adjustments that occur poststimulus (and cue) onset.

The question that is of interest in the current set of experiments is whether reactive control might operate at an even more local level in the color–word Stroop task, and that is the item-level. Motivating this question is Jacoby, Lindsay, and Hessel's (2003) discovery of the *item-specific proportion congruence* (ISPC) effect. The ISPC effect is the finding that Stroop interference is significantly attenuated for items (e.g., BLUE and YELLOW) that are mostly presented in an incongruent color (i.e., yellow and blue, respectively) relative to items (e.g., GREEN and WHITE) that are mostly presented in the congruent color (i.e., green and white, respectively). It is accepted that the ISPC effect, like the CSPC effect, does not reflect the operation of list-level control because the list in which the mostly congruent and mostly incongruent items are embedded is 50% congruent. In other words, because the upcoming trial is equally as likely to be a mostly congruent item as a mostly incongruent item, and control cannot be modulated until the item appears, there is no doubt that the ISPC effect represents the operation of a mechanism that responds reactively to the stimulus.

What is less accepted, however, is the notion that the ISPC effect reflects an item-specific, cognitive control mechanism. The reason this is in doubt is that, unlike the CSPC effect (see Crump & Milliken, 2009), the ISPC effect *can* be explained by simple associative (i.e., contingency) learning because the typical ISPC design confounds proportion congruency and stimulus-response contingency (Jacoby et al., 2003; Schmidt & Besner, 2008). That is, for the set of items that is mostly incongruent (e.g., BLUE and YELLOW), incongruent trials contain a high-contingency response (e.g., BLUE is usually presented in the color yellow and vice versa). For the set of items that is mostly congruent (e.g., GREEN and WHITE), congruent trials contain a high-contingency response (e.g., GREEN is usually presented in the color green). This means that participants can predict the response that is most frequently paired with the word on high-contingency trials (e.g., simply responding "yellow" whenever BLUE is encountered or responding "green" when GREEN is encountered) (cf. Musen & Squire, 1993), thereby speeding responses on these trials, resulting in the ISPC pattern (Schmidt & Besner, 2008). Due to this confound, researchers have been cautious to accept that the ISPC effect implicates a reactive control mechanism that operates at the item-level by rapidly modulating word processing, depending on proportion congruency (i.e., likelihood of experiencing interference for a particular item).

Item-Level Control

In the color–word Stroop task, there is currently no unambiguous evidence for item-specific control because researchers have generally used the design alluded to above, which confounds proportion congruency and contingency (Bugg et al., 2008; Jacoby et al., 2003, Experiments 2a, 2b, & 3; Leboe & Mondor, 2007; Schmidt & Besner, 2008, Reanalyses; but see Hutchison, 2011, for an examination of contingency effects within mostly incongruent items). One study that has demonstrated item-specific control employed the picture–word Stroop task (i.e., name the animal in the picture while ignoring a superimposed animal word; Bugg, Jacoby, & Chanani, 2011, Experiments 1 and 2). Item-specific control was revealed by utilizing a novel design that unconfounded proportion congruency and contingency by designating the relevant dimension (the picture) as the signal of proportion congruency (see Bugg, Jacoby, et al.; Table 1). Unlike the irrelevant dimension (the word), which was used to signal proportion congruency in prior color–word ISPC studies (Bugg et al., 2008; Jacoby et al., 2003, Experiments 2a, 2b, & 3; Schmidt & Besner, 2008, Reanalyses), the relevant dimension is not differentially correlated with responses for different combinations of proportion congruency and trial type (congruency). That is, the relevant dimension is 100% predictive of the correct response for all combinations. This means that trials are equated in contingency. Despite the fact that participants could not differentially predict the correct responses on particular trial types via contingency learning, Bugg, Jacoby, et al. obtained an ISPC effect. Further corroborating the view that the ISPC effect they obtained reflected a reactive, cognitive control mechanism, (a) the ISPC effect primarily resulted from differences in incongruent trial RTs for the mostly congruent and mostly incongruent items, as would be expected if item-specific control were modulating reliance on the word (Schmidt & Besner, 2008), and (b) the ISPC effect, and the pattern

Table 1
Frequency of Word-Color Pairings for Mostly Congruent (MC) and Mostly Incongruent (MI) Items Used in Experiment 1 and on the Training Trials in Experiment 2

	Color			
Word	Blue	Red	Green	White
Version 1				
BLUE	36	4	12	12
RED	4	36	12	12
GREEN	4	4	12	12
WHITE	4	4	12	12
Version 2				
BLUE	12	12	4	4
RED	12	12	4	4
GREEN	12	12	36	4
WHITE	12	12	4	36

Note. Assignment of colors to mostly congruent or mostly incongruent conditions (Versions 1 and 2) was counterbalanced across participants.

of an asymmetrical influence on incongruent trials, transferred to a novel set of 50% congruent pictures for which participants had no prior naming experience.

The picture–word findings of Bugg, Jacoby, et al. (2011) indicate that item-specific control does contribute to the ISPC effect; however, the question remains as to whether control can operate this locally in the color–word Stroop task. Dell'Acqua, Job, Peressotti, and Pascali (2007) have suggested that different mechanisms underlie interference in color–word and picture–word tasks (see van Maanen, van Rijn, & Borst, 2009, for a competing view). Using a psychological refractory period paradigm, Dell'Acqua et al. concluded that interference emerges during the perceptual encoding stage in picture–word Stroop, whereas the locus of the interference effect in color–word Stroop is the later, response-selection stage. For present purposes, this may be an important difference, given that reactive mechanisms such as item-specific control are believed to be triggered by the occurrence of conflict, according to accounts such as the dual-mechanisms-of-control account (Braver et al., 2007) and the item-specific, conflict-monitoring model (Blais, Robidoux, Risko, & Besner, 2007). That is, it is possible that item-specific control is restricted to those paradigms wherein interference (conflict) arises earlier, during perceptual selection. Item-specific control may not effectively trigger attentional adjustments in paradigms wherein interference arises later, during response selection, a point at which it is possibly too late to bias attention toward or away from the word.

The tectonic theory of Stroop effects (Melara & Algom, 2003) provides another reason to question whether ISPC effects from the picture–word Stroop task would replicate in the color–word Stroop task. Contributing to this uncertainty is the fact that use of the relevant dimension (i.e., picture) by Bugg, Jacoby, et al. (2011) to signal ISPC hinged on their ability to bias participants' attention toward that dimension. In color–word Stroop, it is well-known that dimensional imbalance (i.e., the efficiency with which the irrelevant [word] and relevant [color] dimensions can be accessed; Melara & Algom, 2003) strongly favor access to the word dimension, and such imbalance is heightened when words are presented at an optimum viewing angle and when voice responses are used (Melara & Mounts, 1993; Virzi & Egeth, 1985), as was the case in the current set of experiments. Dimensional imbalance could produce a strong opposing influence on participants' attention (i.e., pulling their attention toward the word), thereby limiting our ability to bias their attention toward the (more informative) relevant (i.e., color) dimension. If so, this might preclude participants from rapidly modulating attention on a trial-by-trial basis, based on the proportion congruency of each item (as indicated by the relevant dimension; for further discussion of this possibility, see Bugg, Jacoby, et al., 2011).

Present Study

The present study addresses a theoretical debate that centers on the question of whether item-specific control makes any contribution to the reduction in interference that is observed when specific items are associated with a high probability of interference, as compared with a low probability of interference (i.e., the ISPC effect). The ISPC manipulation, like other proportion-congruence manipulations, varies the frequency with which particular color–word pairings (stimuli) are presented, thereby producing correlations between the color and word dimensions. A body of research by Melara and Algom (2003) and their colleagues (e.g., Algom, Dekel, & Pansky, 1996; Dishon-Berkovits & Algom, 2000; Sabri, Melara, & Algom, 2001) has demonstrated that participants learn these correlations and use them to optimize performance (henceforth referred to as the *correlation account*). One might therefore conceive of the present study as addressing the more specific question of what it means to "make use" of the correlations that are present when ISPC is manipulated. In particular, we consider two possibilities: (a) The information conveyed by the correlations is used as a basis for predicting high-contingency responses (the contingency account forwarded by Schmidt & Besner, 2008), and (b) the information conveyed by the correlations is used as a basis for controlling reliance on the distracting word, depending on the proportion congruency signaled by the color or word (the item-specific control account forwarded by Bugg, Jacoby, & Chanani, 2011). The overarching goals were to determine if item-specific control (and not simply contingency learning, Schmidt & Besner) contributes to the ISPC effect in the color–word Stroop task, and to identify factors that modulate reliance on contingency learning versus item-specific control.

In Experiment 1, we put Bugg, Jacoby, et al.'s (2011) item-specific control account to the test, and attempted to determine whether item-specific control is evidenced in color–word Stroop when the relevant dimension is made the potent ISPC signal. To foreshadow, we observed an almost identical pattern of results to Bugg, Jacoby, et al., supporting the item-specific control account. Because this is the first observation of a reactive control mechanism that operates at the item level in color–word Stroop, we sought to replicate and extend this pattern in Experiment 2 by examining whether item-specific control transfers to a novel set of stimuli. In Experiment 3, we return to the traditional ISPC design in which the irrelevant dimension is the ISPC signal, and test the novel prediction that set size modulates the relative contributions of item-specific control and contingency learning to the ISPC effect. Based on the findings of these experiments, we update and expand the item-specific-control account.

Experiment 1

In Experiment 1, we attempted to replicate Bugg, Jacoby, et al.'s (2011) Experiment 2 finding of an ISPC effect that reflects item-specific control. The primary change from the study of Bugg, Jacoby, et al. is that we used a color–word Stroop task instead of a picture–word Stroop task. Most critical to note: We used their design, which unconfounds proportion congruency and contingency, and produces an experimental context in which only the relevant dimension (color) is a potent signal of proportion congruency.

If an ISPC effect is obtained, this suggests that, despite the absence of a confound between proportion congruency and contingency, participants are able to use the information signaled by the relevant dimension to *control* Stroop interference. That is, they learn that colors are correlated with the probability that the word is interfering and direct attention toward or away from the word on this basis (e.g., reduce reliance on word when the probability is high). The ISPC pattern should also be indicative of control in that it should be characterized by an asymmetrical influence of proportion congruency on the incongruent trials (Schmidt & Besner, 2008). If the ISPC effect in the color–word Stroop task is dependent on the presence of a confound between proportion congruency and contingency (i.e., depends on participants' ability to use the signal of ISPC to predict high-contingency responses via contingency learning), then no ISPC effect should be observed in Experiment 1.

Method

Participants. Twenty male and female undergraduates from Montana State University and Washington University in St. Louis participated for a research requirement for a psychology class. All were native English speakers with normal or corrected-to-normal color vision. All participants provided informed consent.

Design and stimuli. A 2 (proportion congruency: mostly congruent vs. mostly incongruent) × 2 (trial type: congruent vs. incongruent) within-subjects design was used. Four color words (BLUE, RED, GREEN, WHITE) and their corresponding colors were used. The items were divided into two sets according to color (blue and red vs. green and white). One set of colors (e.g., blue and red) was designated mostly congruent. Colors in this set were presented 36 times with the congruent word (e.g., BLUE in blue ink), and 4 times with each incongruent word (e.g., RED, GREEN, or WHITE in blue ink). The second set of colors (e.g., green and white) was designated mostly incongruent and colors in this set were presented 36 times with an incongruent word (e.g., 12 presentations of BLUE, RED, and WHITE in green ink) and 12 times with the congruent word (e.g., GREEN in green ink; see Table 1 for the frequency of color–word pairings). As such, colors in the mostly congruent set were 75% congruent and 25% incongruent, while colors in the mostly incongruent set were 25% congruent and 75% incongruent. In contrast, following from the above example, the *words* BLUE and RED were 56% congruent and 44% incongruent while the *words* GREEN and WHITE were 38% congruent and 62% incongruent. Assignment of colors to ISPC level was counterbalanced across participants.

Procedure. Stimuli were presented using E-prime software (Schneider, Eschman, & Zuccolotto, 2002), and a Model 300 PST serial response box (Psychology Software Tools, Pittsburgh, PA) coded the responses. Each individually tested participant was seated approximately 60 cm from a video graphics array (VGA) monitor. Instructions were displayed on the monitor and paraphrased by the experimenter. Participants were instructed to name the ink color, but not the word itself and to respond as quickly and accurately as possible. Participants received 624 trials, with 96 congruent, 96 incongruent, and 16 neutral trials (e.g., %%%%%) in each of three blocks. Each stimulus was presented in 36-point Arial font and centered on a gray background. The stimulus remained on-screen until a voice response was detected. The experimenter then coded the participant's response via keyboard and the next stimulus was presented 1000 ms later. Trials on which the voice key was tripped by extraneous noise or imperceptible speech were coded as scratch trials. Trials were presented in random order within each block. The experimental trials were preceded by 20 practice trials.

Results

The alpha level was set at .05 for all analyses reported herein and partial eta squared (η_p^2) is reported as the measure of effect size. For each participant, RTs less than 200 ms or greater than 3000 ms were removed, excluding < .01% of the trials. Only correct responses were considered for the reaction time (RT) analyses. A separate mean and standard deviation were computed for congruent and incongruent trials for each participant. Arithmetic means for congruent and incongruent trials based on individual participants' trimmed mean RTs and errors are presented in Table 2. The mean RT on neutral trials was 635 ms (SE = 17), and errors occurred on less than 1% of these trials. Neutral trials were not analyzed further.

Item-specific proportion congruence effect. A 2 (proportion congruency: mostly congruent vs. mostly incongruent) × 2 (trial type: congruence vs. incongruent) within-subjects ANOVA was conducted for RT and error rate. Significant main effects of proportion congruence, $F(1, 19) = 20.75$, $MSE = 579$, $\eta_p^2 = .58$ and trial type, $F(1, 19) = 157.36$, $MSE = 1{,}621$, $\eta_p^2 = .89$, were qualified by a Proportion Congruence × Trial Type interaction, $F(1, 19) = 38.01$, $MSE = 402$, $\eta_p^2 = .67$, which indicated the ISPC effect. The Stroop effect was significantly attenuated for items that appeared in a mostly incongruent ink color (M = 85) relative to items that appeared in a mostly congruent ink color (M = 141); see Figure 1). Examination of the means via planned comparisons revealed that, consistent with an item-specific control account, this effect was driven entirely by speeded RTs on incongruent trials in

Table 2
Mean Reaction Times (RTs) and Percent Errors for Congruent and Incongruent Trials for the Mostly Congruent and Mostly Incongruent Items in Experiment 1

Item type	Trial type	M (SE)	% err (SE)
Mostly Congruent	Incongruent	743 (21)	6.9 (0.8)
	Congruent	602 (16)	0.6 (0.2)
	Stroop effect	141*	6.3*
Mostly Incongruent	Incongruent	688 (17)	5.2 (0.8)
	Congruent	603 (18)	0.9 (0.3)
	Stroop effect	85*	4.3*

* $p < .05$.

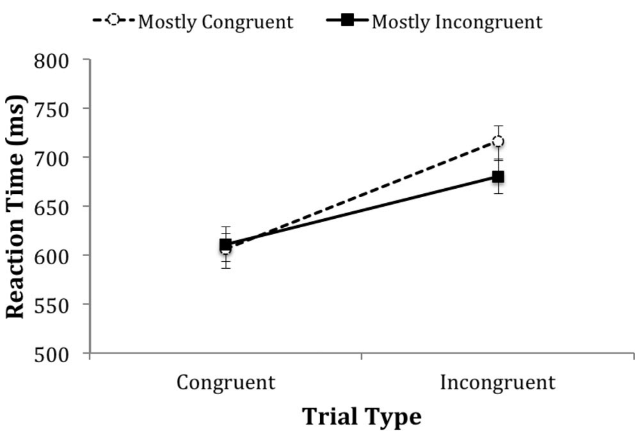

Figure 1. Mean reaction time as a function of trial type and proportion congruence in Experiment 1.

the mostly incongruent (M = 688) as compared with the mostly congruent set (M = 743) $F(1, 19) = 60.40$, $MSE = 500$, $\eta_p^2 = .76$. RTs did not differ for congruent trials from the mostly incongruent (M = 603) and mostly congruent sets (M = 602), $F < 1$.

As for error rate, the main effect of trial type was significant, $F(1, 19) = 58.20$, $MSE = .001$, $\eta_p^2 = .75$. In addition, the Proportion Congruence × Trial Type interaction (i.e., ISPC effect) was significant, $F(1, 19) = 8.11$, $MSE < .001$, $\eta_p^2 = .30$. Consistent with the RT data, the Stroop effect in error rate was less pronounced for items that appeared in a mostly incongruent (M = .043) than a mostly congruent (M = .063) color.

Content-based error analyses. As noted in the method section, when the colors blue and red were mostly congruent, the *words* BLUE and RED were 56% congruent and 44% incongruent. Similarly, when the colors green and white were mostly incongruent, the *words* GREEN and WHITE were 38% congruent and 62% incongruent. It is therefore possible that the learning of these contingencies influenced the performance patterns described above. For example, participants could have learned that the color blue was paired with the word BLUE on 36 trials, whereas the colors red, green, and white were paired with the word BLUE on fewer trials (4, 12, and 12 trials, respectively; see Table 3). Similarly, participants could have learned that the color green was paired with the word GREEN on 12 trials, whereas the colors blue, red, and white were paired with GREEN on 4, 4, and 12 trials, respectively. To address the possibility that contingency learning could be contributing to performance via specific word-color associations, we examined the content of the response that was produced on error trials (3.4% of trials) and calculated the percentage of times each response alternative was produced for each word as a function of the number of times that a response (color) was paired with a word during the task.

Use of contingency learning would be evidenced by two patterns. First, participants should be more likely to respond errantly with colors that were frequently paired with particular words than with those that were infrequently paired with particular words. Second, participants should be most likely to respond errantly with the congruent color for words that are mostly congruent, given it is the single high-contingency response, but not for words that are mostly incongruent. Table 3 presents the average probabilities of producing particular errant responses, collapsed across words as a function of the number of times a particular response (color) was paired with the word. These data are displayed separately for mostly congruent and mostly incongruent words; the words BLUE and GREEN are presented in the table as examples of each item type. As can be seen in Table 3, neither of the above predictions was confirmed. Regarding the first, for the mostly congruent words (e.g., BLUE), red responses (.11) were more probable than either green (.09) or white (.07), despite the fact that green and white were more frequently paired with the word BLUE. Similarly, for the mostly incongruent words (e.g., GREEN), red responses (.08) were more probable than white responses (.06), despite the fact that white was paired with the word GREEN three times as often as red. Consistent with the contingency account, blue responses (.02) were less probable than white responses, with blue being paired with GREEN three times less often than white. However, red and blue, though equally often paired with GREEN, differed most (.08 vs. .02, respectively). More straightforward perhaps are the data pertaining to the second prediction. For the mostly congruent words (.74), and to a greater extent the mostly incongruent words (.83), the most frequently produced errant response was the congruent color. Although frequent production of the high-contingency, congruent response is to be expected for mostly congruent words, the contingency account would not pre-

Table 3
Average Probability With Which Particular Response Alternatives Were Produced on Error Trials in Experiments 1 and 2

Experiment	# of Presentations	Mostly congruent word (BLUE)		# of Presentations	Mostly incongruent word (GREEN)	
		Color			Color	
1	36 (congruent)	blue	0.74	4	blue	0.02
	4	red	0.11	4	red	0.08
	12	green	0.09	12 (congruent)	green	0.83
	12	white	0.07	12	white	0.06
2	36 (congruent)	blue	0.65	4	blue	0.07
	4	red	0.08	4	red	0.03
	12	green	0.11	12 (congruent)	green	0.82
	12	white	0.16	12	white	0.08

Note. The words BLUE and GREEN are used for illustrative purposes only. The probabilities presented within the table reflect the average probability collapsed across *all* words (BLUE, RED, GREEN, and WHITE) separately for the mostly congruent and mostly incongruent items.

dict the congruent response to be the most dominant errant response for the mostly incongruent words.

Discussion

In Experiment 1, an ISPC effect was documented in the color–word Stroop paradigm. Less interference was observed for mostly incongruent than for mostly congruent items, consistent with previous studies (e.g., Blais & Bunge, 2010; Exp 1; Bugg et al., 2008; Exp 1; Jacoby et al., 2003). However, unlike these prior studies, the effect observed here represents the first demonstration of an ISPC effect in a color–word Stroop paradigm that does not appear to be accounted for by contingency learning (i.e., prediction of high-contingency responses; Schmidt & Besner, 2008). Rather, the ISPC effect can be explained by a control mechanism that operates differently for different items. This mechanism takes advantage of the unique color-word correlations that are present for mostly incongruent versus mostly congruent items. The ISPC effect indicates less reliance on the word for items that were presented in a mostly incongruent color (i.e., those for which the correlation between colors and words was a negative one, indicating a low likelihood that the word would be congruent with the color) relative to a mostly congruent color (i.e., those for which the correlation between colors and words was a positive one, indicating a high likelihood that the word would be congruent with the color). The novel feature of this experiment for revealing item-specific control was use of a design in which the relevant (color) dimension functioned as the potent ISPC signal, eliminating the confound between proportion congruency and contingency (i.e., color differentially predicted proportion congruency, but color was perfectly predictive of the correct response for all trial types; cf. Bugg, Jacoby, et al., 2011). The implication is that the ISPC effect observed here, unlike ISPC effects observed previously in color–word Stroop, cannot be accounted for by a contingency-learning mechanism that produces an RT advantage on trials with high-contingency responses (i.e., mostly congruent–congruent and mostly incongruent–incongruent).

The results of the content-based error analyses further corroborate this claim. These analyses examined the possibility that, although participants could not use the colors to predict high-contingency responses, they might still be learning the relationship between words and certain color responses. In other words, they could still be taking advantage of the fact that some words were mostly congruent, here meaning 56%, and some words were mostly incongruent, here meaning 62%, and hence, predicting high or higher frequency responses to these words. Two key findings emerged from these analyses that counter this possibility. First, there was no consistent evidence showing that participants were more likely to errantly produce color responses that had been paired more frequently with particular words than those paired less frequently. Second, the errant response that was most likely to be produced was the congruent response (response corresponding to the word), *both* for mostly congruent words and mostly incongruent words. The latter is unpredicted by a contingency-learning account, given that the congruent color was not the single high-contingency response in the mostly incongruent condition. We suggest that the data, collectively, are consistent with use of item-specific control (i.e., reactive use of the color to control interference).

The findings of Experiment 1 replicate the picture–word Stroop findings of Bugg, Jacoby, et al. (2011; Experiment 2), demonstrating item-specific control. It is important to note, this suggests that even though interference from irrelevant words may arise later in the color–word than in the picture–word Stroop task (Dell'Acqua et al., 2007), item-specific control operates sufficiently rapidly to modulate reliance on word processing. Moreover, the fact that the ISPC effect was obtained when the relevant color dimension functioned as the ISPC signal indicates that participants can override dimensional imbalance in color–word Stroop, when color is useful for the task of minimizing interference (i.e., it is predictive of proportion congruency). Participants' ability to use the color in a goal-relevant fashion may in part reflect that in the current design, attention to the informative color may have been heightened by virtue of the fact that color was technically more salient than is usually the case with color–word Stroop stimuli. This is because each of the four colors was presented equally frequently, whereas two of the words were presented twice as frequently as the other two. As such, the colors were more surprising than the words, and could therefore have attracted greater attention (Melara & Algom, 2003).

The finding of a control-based ISPC effect in Experiment 1 is theoretically significant, in that it is consistent with the correlation account (e.g., Algom et al., 1996; Dishon-Berkovits & Algom, 2000; Melara & Algom, 2003; Sabri et al., 2001) in showing that participants do take advantage of information that is conveyed by the correlations between colors and words. In terms of what it means to take advantage of the information, the current finding challenges the contingency account's claim that ISPC effects have nothing to do with using information about the proportion congruency of particular items, and instead reflect only learning and prediction of the responses most frequently paired with particular items (Schmidt & Besner, 2008). The finding provides further support for Bugg, Jacoby, et al.'s (2011) item-specific-control account, which anticipates the adoption of item-specific control when the ISPC signal shifts to the relevant dimension. This shift is likely irrelevant from the vantage point of the participant who is still simply learning correlations between the color and word dimension, and using them to optimize performance. The shift is, however, relevant from an experimental standpoint in the sense that it limits possible uses of the information conveyed by the correlation. When colors signal ISPC, color is differentially correlated with the likelihood that the word is conflicting with the color, but is not differentially correlated with particular responses. As such, color can be used to modulate attention to the word, but not to predict high-contingency responses.

Like Bugg, Jacoby, et al. (2011, Experiments 1 and 2), the pattern of means representing the ISPC effect in the present experiment indicates an asymmetrical influence of the ISPC manipulation. Participants were faster to respond to the incongruent trials that were presented in mostly incongruent colors, than to the incongruent trials presented in mostly congruent colors; no such difference was observed for congruent trials from the two sets. As postulated by others (Schmidt & Besner, 2008), item-specific control should primarily affect the incongruent trials because the Stroop effect predominantly reflects interference. The fact that no such difference was observed for the congruent trials is also important because it counters an alternative frequency-based account of the ISPC effect. Such an account might posit that the differential frequencies with which participants viewed particular color–word pairings across the two levels of proportion congruency explain the ISPC effect (e.g., Logan, 1988). However, such an account predicts that performance should differ on both incongruent and congruent trials, because both differ in frequency (see Table 1). Yet, no difference in performance was found for congruent trials.

Experiment 2

The control-based ISPC effect found in Experiment 1 is of theoretical importance not only because it challenges the contingency account of ISPC effects (Schmidt & Besner, 2008) but also because it is the first evidence (to our knowledge) of a reactive control mechanism that is operating at the item level in color–word Stroop. Given its significance, we thought it appropriate to replicate the effect. In addition, we aimed to examine whether item-specific control would be transferred to a novel set of 50% congruent items that were presented in a final block of trials. These transfer items consisted of the colors that were mostly congruent (e.g., blue and red) or mostly incongruent (e.g., green and white) in the initial blocks of trials, paired with novel words (YELLOW, BLACK, and PINK; see Table 4). Congruent transfer trials (e.g., YELLOW in yellow) were also presented so as to ensure that the transfer stimuli were 50% congruent. We predicted that, consistent with Bugg, Jacoby, et al. (2011), transfer would be obtained, as indicated by faster response times for novel words presented in a mostly incongruent color than for novel words presented in a mostly congruent color. Such a pattern is consistent with the view that participants use the color to modulate reliance on the word (e.g., attenuate word processing for mostly incongruent colors via item-specific control). If transfer were obtained, it would further counter the contingency- and frequency-based accounts discussed above and, in addition, would refute a second possible account of the control-based ISPC effect. A second account might suggest that the ISPC effect in Experiment 1 was obtained because of a disproportionate presentation of select words (those that correspond to the mostly congruent colors; see Table 1). In the typical ISPC design, each word appears as often as every other word. If item-specific control transfers to a set of stimuli for which all words are presented equally frequently, then this would suggest that control is not dependent on this design artifact.

Method

Participants. Twenty male and female undergraduates from Washington University in St. Louis participated for a research requirement for a psychology class. All were native English speakers with normal or corrected-to-normal color vision. All participants provided informed consent.

Design and stimuli. The design and stimuli were identical to Experiment 1, with the following exceptions. A third factor of item type (training vs. transfer) was manipulated. The first three blocks were identical in composition to the blocks in Experiment 1, though here we refer to the stimuli presented during those blocks as "training items." Transfer items were included in the fourth block of trials, after three blocks of training items were administered. Transfer items were pairings of the mostly congruent and mostly incongruent colors from the training items with three novel words (YELLOW, BLACK, PINK). Of note, the transfer items were 50% congruent. That is, the words YELLOW, BLACK, and PINK were presented equally frequently as congruent trials (e.g., 12 presentations of YELLOW in yellow) and as incongruent trials (e.g., three presentations of YELLOW in each of the colors blue, red, green, and white) (see Table 4). As the example suggests, each training color was presented equally frequently with each transfer word during incongruent trials.

Procedure. The procedure followed Experiment 1, except that in the fourth block, participants received 216 trials. Of these trials, 144 were training items that continued to be presented in accordance with their assignment to mostly congruent and mostly incongruent sets, and 72 were transfer items.

Results

We implemented the same outlier removal procedure used in Experiment 1 and it removed < .01% of the correct RTs. Arithmetic means for congruent and incongruent trials based on individual participants' trimmed mean RTs and errors are presented for training and transfer items in Table 5. The mean RT on neutral trials was 619 ms ($SE = 17$), and errors occurred on less than 1% of neutral trials. Neutral trials were not analyzed further.

Training set. A 2 (proportion congruency: mostly congruent vs. mostly incongruent) × 2 (trial type: congruence vs. incongruent) within-subjects ANOVA was conducted for RT and error rate. For RT, the main effects of proportion congruence, $F(1, 19) = 5.76$, $MSE = 823$, $\eta_p^2 = .23$ and trial type, $F(1, 19) = 166.95$, $MSE = 961$, $\eta_p^2 = .90$ were significant. Most importantly, the interaction was significant, indicative of the ISPC effect, $F(1, 19) = 21.83$, $MSE = 372$, $\eta_p^2 = .54$. Significantly less interference was observed for items that were presented in a mostly incongruent ink color ($M = 69$) than in a mostly congruent ink color ($M = 110$). Also replicating Experiment 1, an asymmetrical influence of

Table 4
Frequency of Word–Color Pairings for the Transfer Trials in Experiment 2

	Color						
WORD	blue	red	green	white	pink	black	yellow
PINK	3	3	3	3	12	0	0
BLACK	3	3	3	3	0	12	0
YELLOW	3	3	3	3	0	0	12

Note. The composition of the transfer trials was identical for Versions 1 (where blue and red served role as mostly congruent items) and 2 (where green and white served role as mostly congruent items).

Table 5
Mean Reaction Times (RTs) and Percent Errors for Congruent and Incongruent Trials for the Mostly Congruent and Mostly Incongruent Items in Experiment 2

Item type	Trial type	*M* (*SE*)	% err (*SE*)
Mostly congruent	Incongruent	716 (21)	3.4 (0.6)
	Congruent	606 (17)	0.3 (0.1)
	Stroop effect	110*	3.1*
Mostly incongruent	Incongruent	680 (24)	1.4 (0.3)
	Congruent	611 (20)	0.4 (0.2)
	Stroop effect	69*	1.0*
Transfer items	Mostly congruent–incongruent	747 (22)	5.1 (0.1)
	Mostly incongruent–incongruent	717 (23)	3.5 (0.1)
	Congruent	623 (14)	1.6 (0.1)

* $p < .05$.

the proportion-congruence manipulation was found. The manipulation had a significant effect on the incongruent trials, $F(1, 19) = 14.24$, $MSE = 888$, $\eta_p^2 = .43$ but not the congruent trials, $F < 1$.

For error rate, significant main effects of proportion congruence, $F(1, 19) = 10.69$, $MSE < .001$, $\eta_p^2 = .36$ and trial type, $F(1, 19) = 34.75$, $MSE < .001$, $\eta_p^2 = .65$ were qualified by a significant Proportion Congruence × Trial Type Interaction, $F(1, 19) = 10.86$, $MSE < .001$, $\eta_p^2 = .36$. Significantly more errors were made for items in the mostly congruent condition ($M = .031$) than for items in the mostly incongruent condition ($M = .010$).

Content-based error analyses. As in Experiment 1, we addressed the possibility that contingency learning could be contributing to the performance patterns on the training trials by examining the predictions regarding the average probability with which particular errant responses (which occurred on <1.5% of trials in this experiment) were produced to each word.

As indicated in Table 3, for the mostly congruent words (e.g., BLUE), red responses (.08) were less probable than either green (.11) or white (.16). This is consistent with the contingency account because red was paired with blue four times, whereas green and white were each paired 12 times. However, the contingency account would have predicted three times as many "green" and "white" responses as "red," and more similar probabilities for green and white. For the mostly incongruent words (e.g., GREEN), blue responses (.07) and white responses (.08) were equally probable. This is inconsistent with the contingency account because white was paired with the word GREEN three times as often as blue. Red responses (.03) were less probable than white responses (.08), which is consistent with the contingency account because white was paired with GREEN three times as often as red. Perhaps the clearest pattern that runs in opposition to the predictions of the contingency account is the finding that, similar to Experiment 1, the most frequently produced errant response was the congruent color for not only mostly congruent words (.65) but also, and to a greater degree, for mostly incongruent words (.82), although no single high-contingency congruent response existed for the latter.

Transfer set. Transfer was examined for the 17 participants who showed a positive ISPC effect on the training items (e.g., those who showed less interference for the mostly incongruent than for mostly congruent items), because no transfer would be predicted for participants ($N = 3$) who did not demonstrate this pattern. As hypothesized, a one-tailed dependent *t* test indicated that RT was significantly faster on the transfer items that appeared in a mostly incongruent color ($M = 717$, $SE = 23$) than on those that appeared in a mostly congruent color ($M = 747$, $SE = 22$), $t(16) = 1.97$, $\eta_p^2 = .20$. There was no difference in error rate across the two types of transfer items, $F < 1$.

Discussion

Replicating Experiment 1, we observed an ISPC effect on the training trials, consistent with the item-specific control account (Bugg, Jacoby, et al., 2011). As with the ISPC effect observed in Experiment 1, the design precludes it from being accounted for by a mechanism that predicts high-contingency responses on the basis of the ISPC signal (the color). Additionally, the content-based error analyses suggest that, although there was slight evidence for use of the word to predict responses via contingency learning, the evidence was weak and inconsistent, with some findings clearly disconfirming the contingency account (e.g., the finding that the congruent response was the most likely errant response for mostly incongruent words). The results of these analyses should, however, be interpreted with caution, because the error rate for training trials was <1.5% in this experiment; the analyses may therefore be less trustworthy than those of Experiment 1 (where the error rate was 3.4%). As one indicator of the high variability that such a low overall error rate can produce, zero errors were made in 30% of the mostly incongruent cells in Experiment 2 (as compared with 6% in Experiment 1).

Extending Experiment 1, and more directly refuting the contingency account, we found that participants transferred item-specific control settings to a novel set of 50% congruent items. These were items for which participants had no prior naming experience (e.g., PINK in blue ink) and, therefore, for which responses could not be predicted. Participants were significantly faster to respond to new words that were presented in a mostly incongruent color than to new words that were presented in a mostly congruent color. Theoretically, this finding implies that participants learned to use the color of training items as a signal of proportion congruency, or the likelihood that the word would interfere with the color, again consistent with the correlation account (e.g., Algom et al., 1996; Dishon-Berkovits & Algom, 2000; Melara & Algom, 2003; Sabri et al., 2001). Moreover, they generalized use of this signal to transfer items, thereby permitting rapid control over the reading of the novel words.

One might characterize the item-specific control mechanism as a word-reading filter (Jacoby et al., 2003; Jacoby, McElree, & Trainham, 1999). If so, the finding of transfer suggests a filter that is not specific to particular words, but generalizes to other words, and might as such be thought of as a more flexible, shape-based filter. Alternatively, item-specific control might reflect differential reliance on the word response. That is, because the word response tends to be activated prior to the color response and is thus available at the point the color is processed, the color might be used to modulate reliance on the already activated word response (e.g., dampening its activation in the case of a mostly incongruent item, or relying on it more heavily in the case of a mostly congruent item). Regardless of its characterization, one question is why such a mechanism would selectively affect incongruent trials, as was found in Experiment 1 and Experiment 2. One possibility, which is true to Braver et al.'s (2007) notion of reactive control mechanisms being conflict-driven, is that control (e.g., the filter) is activated in response to the occurrence of conflict (i.e., interference), which occurs exclusively on incongruent trials. Importantly, such a view is also consistent with extant models that include an item-specific conflict-monitoring module (Blais et al., 2007; Verguts & Notebaert, 2008).

The finding of transfer is also important in that it rules out alternative accounts of the control-based ISPC effect observed in this experiment and in Experiment 1. One such account is a frequency-based account (e.g., Logan, 1988). The mostly incongruent and mostly congruent colors were paired equally frequently with each word in the set of transfer items. The fact that performance was nonetheless faster when the words were presented in mostly incongruent colors is inconsistent with a frequency-based account. It should also be noted that, as in Experiment 1, the finding that the ISPC effect did not reflect a difference in performance on the congruent trials is inconsistent with a frequency-based account. A second, possible account is that the control-based ISPC effect stems from the disproportionate presentation of select words (those that are associated with mostly congruent colors). Because the transfer words were presented equally often in mostly incongruent and mostly congruent colors, and transfer of item-specific control was still observed, such an account is refuted.

Experiment 3

Experiments 1 and 2 provided initial evidence for item-specific control in the color–word Stroop task, and further evidence in support of the item-specific control account (Bugg, Jacoby, et al., 2011). Experiments 1 and 2, however, differed in several respects from past color–word Stroop studies, for which ISPC effects could alternatively be explained by a contingency mechanism (e.g., Jacoby et al., 2003). The primary difference was the use of a design in which the relevant dimension (color) was designated to be the potent signal of ISPC, which unconfounded proportion congruency and contingency. To date, there is no evidence that item-specific control contributes to the ISPC effect in the traditional design, in which the irrelevant dimension (word) is the potent signal of proportion congruency, and proportion congruency and contingency are confounded (e.g., Blais & Bunge, 2010; Bugg et al., 2008; Jacoby et al., 2003). This is the design from which the contingency-learning hypothesis was formulated (Schmidt & Besner, 2008). We therefore return to this design in Experiment 3, and examine a theoretically important factor that we believe might moderate use of the correlations between the words and colors as a basis for item-specific control versus contingency learning.

In particular, we investigate the novel prediction that set size moderates the contribution of item-specific control to the ISPC effect (cf. Bugg et al., 2008; Bugg & Chanani, 2011; Hutchison, 2011). Most previous color–word Stroop studies that examined and theorized about ISPC effects (Jacoby et al., 2003, Experiments 2a, 2b, 3; see also Blais & Bunge, 2010, Experiment 1; Bugg et al., 2008, Experiment 1) used a design in which words were designated to be mostly incongruent or mostly congruent, and these sets did not overlap (e.g., words from the mostly incongruent set never appeared in the colors from the mostly congruent set), unlike in Experiments 1 and 2 of the current study. In the most common instantiation of this design (Blais & Bunge, 2010; Bugg et al., 2008; Jacoby et al., 2003, Experiments 2a, 2b, & 3), two words are assigned to the mostly congruent set and two are assigned to the mostly incongruent set. Schmidt and Besner (2008) showed that the resulting ISPC effect is accounted for by contingency learning. We do not dispute the contribution of contingency learning to ISPC effects that emerge in designs of this nature. However, the contingency-learning account may be limited to explaining ISPC effects that result from designs in which a small set size (e.g., two) is employed.

We propose that a set size of two promotes reliance on a contingency learning mechanism because a single, high-contingency response exists for the mostly congruent and mostly incongruent set of items (see boxed cells in top-half of Table 6). That is, a high-contingency response exists for mostly congruent–congruent trials and for mostly incongruent–incongruent trials in a 2-item set. It is therefore advantageous to use the word-color correlations to predict high-contingency responses on the majority of trials. A set size of four, by contrast, should promote reliance on item-specific control, because unlike in a 2-item set, there is no high-contingency response for the mostly incongruent set (see lower half of Table 6). Instead, there are three response options, all of which are equally likely (i.e., contingent on the word) on mostly incongruent–incongruent trials. Increasing the set size, thus, has the effect of making it impossible to predict a high-contingency response on any incongruent trial in the task. This effect, therefore, might lead to a shift in how the correlations between words and colors are used, with it being a basis for adjusting item-specific control in a 4-item set.

Unlike Experiments 1 and 2, the obtainment of an ISPC effect in Experiment 3 would not be strongly diagnostic of the underlying mechanism (use of item-specific control vs. contingencies), because either could be contributing given the confound between proportion congruency and contingency. Therefore, to evaluate the contribution of item-specific control and contingency learning to the ISPC effect in the 2- and 4-item sets, we used a two-tiered approach. First, we used planned comparisons to examine the size of the proportion congruent effect (mostly congruent vs. mostly incongruent) separately for congruent and incongruent trials in

Table 6
Frequency of Word-Color Pairings for Mostly Congruent (MC) and Mostly Incongruent (MI) Items Used in the 2-Item and 4-Item Sets in Experiment 3

			Color							
Set	Cond	WORD	blue	white	green	pink	red	black	yellow	purple
2-Item set (Version 1)										
	MC	BLUE	**72**	18						
		WHITE	18	**72**						
	MI	RED					18	**72**		
		BLACK					**72**	18		
2-Item set (Version 2)										
	MC	GREEN			**72**	18				
		PINK			18	**72**				
	MI	YELLOW							18	**72**
		PURPLE							**72**	18
4-Item Set										
	MC	BLUE	**36**	3	3	3				
		WHITE	3	**36**	3	3				
		GREEN	3	3	**36**	3				
		PINK	3	3	3	**36**				
	MI	RED					9	12	12	12
		BLACK					12	9	12	12
		YELLOW					12	12	9	12
		PURPLE					12	12	12	9

Note. Assignment of words to mostly congruent or mostly incongruent conditions was counterbalanced across participants. Boldface for a given frequency denotes that this trial type is one for which a high-contingency response exists. Note that there are no trial types of this sort in the MI condition of the 4-Item Set.

each set.[1] For the 2-item set, the contingency account would predict that the size of proportion-congruent effects should be equal for congruent and incongruent trials. Specifically, because Stroop and contingency are hypothesized to affect different processes (Schmidt & Besner, 2008), participants should be faster when the word validly predicts the color (i.e., on a high- relative to low-contingency trial), regardless of whether the trial itself is congruent or incongruent. If item-specific control were dominating in the 2-item set, larger proportion-congruent effects should be observed for incongruent trials than for congruent trials (Schmidt & Besner).

For the 4-item set, a contingency account would predict little-to-no proportion-congruence effect on incongruent trials, because such trials have no single high-contingency response for either the mostly incongruent or mostly congruent condition. However, the contingency account would predict a large proportion-congruence effect on congruent trials because these trials contain a high-contingency response in the mostly congruent, but not mostly incongruent, condition. A control account, in contrast, would continue to predict larger effects of proportion congruence on the incongruent trials than on the congruent trials (Schmidt & Besner, 2008). We predicted that the pattern of results would support a contingency account for the 2-item set (i.e., equal proportion-congruence effects on congruent and incongruent trials), and the control account for the 4-item set (i.e., larger proportion-congruence effects on incongruent trials).

We also employed a second and more direct approach to examining whether the ISPC effects were entirely contingency-based or reflected item-specific control. The second approach was to examine performance on a set of transfer items that were embedded in a final block of trials after participants had two blocks of experience with the mostly congruent and mostly incongruent items in the training sets. Because the contingency-learning hypothesis explains the ISPC effect through the learning of high-contingency responses (e.g., respond yellow to the word BLUE), the contingency-learning hypothesis predicts no transfer of the ISPC effect to new colors that were absent during training. Two new colors (orange and brown) were therefore introduced in the final block of trials, and previously trained, mostly congruent and mostly incongruent words were occasionally presented in orange or brown. We also included congruent transfer trials, with the words ORANGE and BROWN presented in orange and brown, respectively. This permitted us to calculate Stroop interference. If use of a 4-item set, but not a 2-item set, facilitates use of item-specific control, then the Stroop effect should be smaller for the mostly incongruent relative to the mostly congruent transfer items, selectively in those participants who received the 4-item set (i.e., an ISPC effect). The rationale is that only a control mechanism that modulates the influence of word reading based on the word's previous proportion congruency could produce this transfer effect.

[1] Schmidt and Besner (2008) developed a contingency analysis for purposes of examining whether a contingency account explains ISPC effects. However, the analysis relies on the assumption that a high-contingency "cell" exists for both the mostly congruent and mostly incongruent conditions. This assumption holds for the 2-item set, but is violated when more than one incongruent response option exists for mostly incongruent trials, as in the case of the 4-item set. In order to be consistent in our approach to evaluating the contributions of contingency learning and item-specific control to the ISPC effect in the 2- and 4-item sets, we used the planned comparisons described in the text, and not the contingency analysis.

This is because the transfer colors have no preexisting association with the trained words; in fact, they are equally contingent on words from the mostly congruent and mostly incongruent sets (in both the 2-item and 4-item conditions).

Method

Participants. Sixty-seven male and female Montana State University undergraduates participated for a research requirement for an introductory psychology class. All were native English speakers with normal or corrected-to-normal color vision. Data were excluded from three students whom had more than 20% total microphone errors. The data are therefore reported from 64 total participants, 32 in each set-size condition. All participants provided informed consent.

Stimuli. Ten color words and their corresponding colors were used in this experiment, eight for the training set and two as transfer items. The eight training stimuli were divided into two sets (BLUE, WHITE, GREEN, PINK vs. RED, BLACK, YELLOW, PURPLE). For the 2-item set condition, participants received either the first or last two items in each set (see Versions 1 and 2 in Table 6), with the four selected words and colors presented 90 times for each participant. Mostly congruent items for the 2-item sets were presented in their congruent color on 72 trials (80%) and in the incongruent color on 18 trials (20%). This pattern was reversed for mostly incongruent items. For the 4-item set, all eight words and colors were presented 45 times for each participant (see Table 6). The four words in the mostly congruent set were presented in their own color on 36 trials (80%) and presented three times in each of the three possible incongruent colors (20%) within the set. The four words in the mostly incongruent set occurred in their own color on nine trials (20%) and occurred 12 times in each of the three incongruent colors (80%) from that set. For both the 2-item and 4-item set conditions, assignment of critical color sets to the mostly congruent and mostly incongruent conditions was counterbalanced across participants.

In addition to the eight items used in the training set, the words and colors brown and orange were included within a third block of trials to assess transfer of ISPC effects. Participants received 12 (incongruent) transfer trials for mostly incongruent training words and 12 (incongruent) transfer trials for mostly congruent training words. In the 2-item set condition, the two mostly congruent words and two mostly incongruent words were presented three times in each of the two transfer colors. In the 4-item set condition, two of the four mostly congruent training words were presented twice in brown and once in orange, while the other two were presented once in brown and twice in orange. The same was true for the mostly incongruent training words. As such, the total number of incongruent transfer trials was equated for the 2- and 4-item set conditions. In addition to these 24 incongruent transfer trials, 24 congruent transfer trials were included in which the words BROWN or ORANGE were presented in their congruent color, such that the transfer stimuli were 50% congruent. This permitted us to examine the Stroop effect (incongruent RT–congruent RT) for the transfer items.

Design. For the main training set, we utilized a 2 (proportion congruency: mostly congruent vs. mostly incongruent) × 2 (trial type: congruent vs. incongruent) × 2 (set size: 2-item vs. 4-item) mixed design. Proportion congruency and trial type were manipulated within participants; set size was manipulated between participants. For the transfer set, we examined RT and errors for participants in the 2-item and 4-item sets when they responded to trained, mostly congruent words presented in transfer colors; trained, mostly incongruent words presented in transfer colors; or transfer words presented in their congruent transfer colors.

Procedure. The procedure was identical to Experiment 1 with the following exceptions. Participants received 392 total experimental trials, with 120 trials occurring in each of the first two training blocks. The third block contained 152 trials, with 104 training stimuli that continued to be presented in accordance with their proportion congruency assignments from the previous two blocks, and 48 transfer trials. Each stimulus was presented for 3,000 ms or until a response was given and was preceded by a 1,000 ms interstimulus interval. Stimuli were presented in a random order that was the same for all participants. An experimenter sat next to the participant, held a sheet with the correct (color) responses for each trial and coded participants' responses as (a) correct response, (b) response error, or (c) microphone error (scratch trial) with his or her right hand. Response errors consisted of responding with the wrong word (e.g., responding "green" to the word GREEN written in blue), or with a blended word (e.g., "gre-blue"). Holding the correct answers in front of them allowed the experimenters to accurately record participants' responses. Experimental trials were preceded by 16 randomly presented practice trials.

Results

We implemented the same outlier removal procedure used in Experiments 1 and 2, and it removed less than .01% of the correct RTs for participants in either the 2-item or 4-item set conditions. Arithmetic means based on individual participants' trimmed-mean RTs and errors are presented in Table 7 for the training set and Table 8 for the transfer set.

Training set. RTs and errors were analyzed using mixed ANOVAs, with proportion congruence (mostly congruent vs. mostly incongruent) and trial type (congruent vs. incongruent) as within-subject variables, and set size (2 vs. 4) as a between-subjects variable. In the RT analysis, overall RTs were marginally faster among participants in the 4-item set, $F(1, 62) = 2.96$, $MSE = 29{,}682$, $\eta_p^2 = .05$. The overall Stroop effect (i.e., main effect of trial type) was significant, $F(1, 62) = 392.33$, $MSE = 2{,}377$, $\eta_p^2 = .86$, and significantly interacted with proportion congruence, $F(1, 62) = 155.34$, $MSE = 576$, $\eta_p^2 = .72$, demonstrating the standard ISPC effect (Jacoby et al., 2003). Finally, there was a significant 3-way Proportion Congruence × Trial Type × Set Size interaction, $F(1, 62) = 5.65$, $MSE = 576$, $\eta_p^2 = .08$, in which the ISPC effect was larger for the 2-item set ($M = 89$ ms) than for the 4-item set ($M = 61$ ms), although both effects were significant (both $ps < .001$).

The next step was to conduct the planned comparisons to examine if the ISPC effect was driven more strongly by incongruent or congruent trials, and if this differed depending upon set size. Thus, for incongruent trials, this difference was computed as mostly congruent–mostly incongruent, whereas for congruent trials, this difference was computed as mostly incongruent–mostly congruent. Both proportion-congruence effects were significant in the 2-item and 4-item sets. However, as can be seen in Figure 2,

Table 7
Mean Reaction Times (RTs) and Percent Errors for Mostly Congruent and Mostly Incongruent Training Items From 2-Item or 4-Item Sets Presented on Congruent and Incongruent Trials in Experiment 3

		2-item set ($N = 32$)		4-item set ($N = 32$)	
Item type	Condition	*M* (*SE*)	% err (*SE*)	*M* (*SE*)	% err (*SE*)
Mostly congruent	Incongruent	780 (18)	8.1 (1.4)	745 (19)	7.9 (1.1)
	Congruent	619 (12)	0.2 (0.1)	590 (14)	0.1 (0.0)
	Stroop effect	161*	7.9*	155*	7.8*
Mostly Incongruent	Incongruent	734 (18)	3.8 (0.5)	703 (16)	4.0 (0.4)
	Congruent	662 (16)	0.4 (0.2)	609 (15)	0.1 (0.1)
	Stroop effect	*72**	*3.5**	*94**	*3.9**

* $p < .05$.

the results for the 2-item set fit the predictions of the contingency account, with symmetrical proportion congruency effects on congruent ($M = 43$ ms) and incongruent ($M = 46$ ms) trials, $F < 1$ for the difference in proportion-congruency effects between congruent and incongruent trials. In contrast, the results for the 4-item set support the control hypothesis. Specifically, proportion congruence effects were larger for incongruent ($M = 42$ ms) than congruent ($M = 19$ ms) trials, $F(1, 31) = 8.33$, $MSE = 500$, $\eta_p^2 = .21$.

In the error analysis, there was an overall effect of trial type, $F(1, 62) = 104.89$, $MSE = 22$, $\eta_p^2 = .63$, indicating an overall Stroop effect and of proportion congruence, $F(1, 62) = 24.66$, $MSE = 11$, $\eta_p^2 = .29$, indicating greater errors for mostly congruent items. As with the RT analysis, there was again a significant ISPC effect, $F(1, 62) = 29.77$, $MSE = 10$, $\eta_p^2 = .32$, such that Stroop effects were larger for mostly congruent items ($M = 8.1\%$) than mostly incongruent items ($M = 3.7\%$). No other effects reached significance.

Transfer set. As in Experiment 2, we limited the analysis of transfer to those participants who demonstrated ISPC effects on the training trials. In both the 2-item and 4-item sets, 30 out of 32 participants showed a positive ISPC effect. In the transfer set, there were two incongruent conditions and one congruent condition. Participants responded to trained, mostly congruent words; trained, mostly incongruent words; or transfer words presented in the transfer colors (brown or orange). The same congruent condition (transfer words in transfer colors) was therefore used to calculate a Stroop effect for both levels of proportion congruence (mostly congruent vs. mostly incongruent). Stroop effects in RTs and errors were analyzed using mixed ANOVAs, with proportion congruence (mostly congruent vs. mostly incongruent) as a within-subject variable, and set size (2 vs. 4) as a between-subjects variable. In the RT analysis, there was a significant Proportion Congruence × Set Size Interaction, $F(1, 58) = 5.42$, $MSE = 2{,}526$, $\eta_p^2 = .09$, in which transfer of the ISPC effect to new colors was greater for those participants in the 4-item set than in the 2-item set. Paired sample *t* tests revealed that the 34 ms transfer effect among those in the 4-item group was significant, $t(29) = 2.74$, $SEM = 12$, $\eta_p^2 = .21$, but the −9 ms transfer effect from those in the 2-item group was not, $t(29) = -.65$, $SEM = 14$, $\eta_p^2 = .01$. In the error analysis, neither main effect nor the interaction approached significance (all *p*s > .16). Similarly, paired-sample *t* tests revealed that neither the 2-item nor the 4-item transfer effects were significant (both *p*s > .19).

Discussion

We found a significant ISPC effect for both the 2-item set and the 4-item set, although it was statistically larger for the 2-item set, a pattern that we return to momentarily. As discussed above, the mere presence of the effect is not indicative of the underlying mechanism that contributed in the 2-item and 4-item set conditions. However, there are two findings that argue strongly for different mechanisms governing the ISPC effect for small and large set sizes. First, the ISPC pattern in the 2-item set matched the pattern predicted by the contingency-learning hypothesis, in which effects of ISPC are equal for congruent and incongruent trials. In

Table 8
Mean Reaction Times (RTs) and Percent Errors for Trained, Mostly Congruent or Mostly Incongruent Words From 2-Item or 4-Item Sets Presented in Transfer Colors in Experiment 3

		2-item set ($N = 30$)		4-item set ($N = 30$)	
Condition	Word type	*M* (*SE*)	% err (*SE*)	*M* (*SE*)	% err (*SE*)
Incongruent	Mostly congruent	788 (23)	6.5 (1.3)	802 (21)	6.9 (1.3)
	Mostly incongruent	797 (23)	4.3 (1.3)	768 (20)	6.2 (1.3)
Congruent	Transfer word	641 (13)	0.7 (0.4)	614 (13)	0.1 (0.1)
	MC Stroop effect	147*	5.8*	188*	6.8*
	MI Stroop effect	156*	3.6*	154*	6.1*
	ISPC Stroop diff:	−9	2.2	34*	0.7

* $p < .05$.

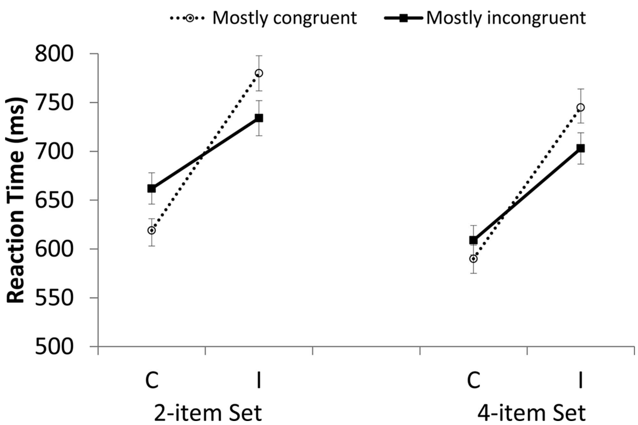

Figure 2. Mean reaction time as a function of trial type (C = congruent, I = incongruent) and proportion congruence for the 2-item and 4-item set conditions in Experiment 3.

contrast, the ISPC pattern in the 4-item set matched the pattern predicted by the item-specific control hypothesis, in which the use of proportion congruency to modulate reliance on the word has a larger effect on incongruent trials.

Providing converging evidence for our prediction that use of a 4-item set leads to reliance on item-specific control, whereas use of a 2-item set leads to reliance on contingency learning, significant transfer of the ISPC pattern was observed only in the 4-item set condition. Specifically, in the 4-item set, less Stroop interference was observed for words from the mostly incongruent condition that were presented in novel (untrained) colors than for words in the mostly congruent condition presented in those same colors. In the 2-item set, no evidence of transfer was apparent; in fact, participants were nominally slower in responding to mostly incongruent words in novel colors relative to mostly congruent words, which is counter to the pattern one would expect if there was transfer.

Critically, the presence of transfer in the 4-item set also indicates that the word, and not the color or the color–word compound, was used as the signal of proportion congruence (i.e., the signal that determines filtering of the word; cf. process-dissociation estimates for ISPC manipulation, Jacoby et al., 2003). The implication is that the differential patterns obtained across the 4- and 2-item set conditions do not simply reflect use of different proportion congruency (or, in the case of the 2-item set, contingency) signals (e.g., word for the 2-item set, color–word compound, or color for the 4-item set).

The findings of Experiment 3 support the idea that set size is a theoretically important factor influencing the mechanism at play in ISPC studies. Larger set sizes (e.g., 4-items) appear to promote use of item-specific control whereas smaller set sizes (e.g., 2-items) promote reliance on contingency learning. That the ISPC effect is larger in the 2-item set may reflect that contingency learning produces relatively large, and similarly sized effects on the congruent and incongruent trials, whereas when item-specific control dominates (i.e., in the 4-item set), it produces a more pronounced effect on incongruent trials and a relatively smaller effect on congruent trials. These patterns support the view that contingency learning plays a role in the obtainment of the ISPC effect, but show that this mechanism cannot account for all ISPC effects. Contingency learning dominates in a 2-item set, but in the case of a 4-item set, the ISPC effect also reflects item-specific control. We attribute this pattern to the fact that high-contingency incongruent responses do not exist when the stimulus set size increases beyond two items (see Hutchison, 2011, for an exception). Thus, contingency learning is of limited utility in attenuating interference for larger set sizes.

General Discussion

Two novel lines of evidence from the present set of experiments demonstrate the operation of item-specific control in the color–word Stroop task. One line stems from Experiments 1 and 2, where we observed an ISPC effect when the color was used as the signal of proportion congruence. The absence of any differences in contingency level across combinations of proportion congruence and trial type, along with the content-based error analyses in Experiments 1 and 2 and the evidence of transfer in Experiment 2, indicate that contingency-learning mechanisms play little if any role in the obtainment of the ISPC effect. In contrast, item-specific control, the modulation of the word's influence on an item-by-item basis, can explain the obtainment of the effect as well as the selective influence of the ISPC manipulation on incongruent trials. This is the same pattern that was observed when item-specific control was documented in the picture–word Stroop task (Bugg, Jacoby, et al., 2011, Experiments 1 and 2). The fact that it replicated in color–word Stroop is telling, in that it suggests that (a) even if conflict occurs relatively late in color–word as compared with picture–word Stroop (Dell'Acqua et al., 2007), item-specific control is sufficiently rapid, such that reliance on the word can still be modulated, and (b) the dimensional imbalance that characterizes color–word Stroop (Melara & Algom, 2003) does not preclude use of information about proportion congruency that is signaled by the relevant dimension, at least when color is more salient than is usually the case with color–word stimuli.

A second line of evidence supporting item-specific control stems from Experiment 3, where the more traditional design (in which words were designated mostly incongruent or mostly congruent) was implemented, and the sets were not permitted to overlap. Here, we observed an ISPC effect in both the 2-item set and 4-item set condition; however, evidence for item-specific control was exclusively found for the 4-item set condition. As in Experiments 1 and 2, this evidence included the observation that the ISPC manipulation had a more robust influence on performance on the incongruent trials, a pattern anticipated to accompany item-specific control (Schmidt & Besner, 2008). This evidence also included the novel obtainment of transfer of item-specific control in the 4-item set condition. Participants showed less interference in naming new ink colors for mostly incongruent than for mostly congruent words. In contrast to these patterns, when the item-specific sets were composed of two items, the dominant mechanism was contingency learning. The symmetrical effects of the ISPC manipulation on congruent and incongruent trials and the absence of transfer support this conclusion.

To our knowledge, these findings represent the only unambiguous evidence supporting the contribution of item-specific control to ISPC effects in the color–word Stroop paradigm. There are several important theoretical implications of these findings. First, they confirm the view that control operates at multiple levels in the color–word Stroop task. In line with the dual-mechanisms of control account, our findings show that control can operate reactively, following stimulus onset, to modulate interference in the color–word Stroop task (Braver et al., 2007). On the one hand, this conclusion echoes that which stems from studies that have revealed context-specific proportion congruence (CSPC) effects (e.g., Crump et al., 2006). The CSPC effect, like the ISPC effects obtained in Experiments 1 and 2 and in the 4-item set-size condition of Experiment 3, cannot be explained by a contingency-learning mechanism, and generalizes to transfer items (Crump & Milliken, 2009). On the other hand, it may not be appropriate to equate the two types of effects. Rather, the current findings are important in showing that control can operate at a level that is even more local than the contextual level: the item level.

This conclusion becomes apparent when one considers that in the ISPC paradigm, a single stimulus (e.g., GREEN in white) is *either* mostly congruent or mostly incongruent. In the CSPC paradigm, a single stimulus (e.g., GREEN in white) appears *both* in the mostly congruent and mostly incongruent context (e.g., location). As such, in the CSPC but not the ISPC paradigm, more than one control setting is applied to each stimulus. When the stimulus appears in the mostly congruent location, processing of the word is not attenuated, whereas when the same stimulus appears in the mostly incongruent location, processing is attenuated. There are no item-specific features that dictate which control setting should be used, only a context-specific feature. In the ISPC paradigm, by contrast, if the stimulus GREEN in white is assigned to the mostly incongruent condition, a single level of control is applied to that item. In other words, control is item-specific. The difference in the level at which control operates is also made apparent when one considers how transfer is assessed in the CSPC and ISPC paradigms. In the CSPC paradigm, the same, novel transfer stimulus appears in both contexts, and interference is reduced when it appears in the mostly incongruent context (Crump & Milliken, 2009). In the ISPC paradigm, an item-specific feature (e.g., the mostly incongruent word GREEN or the mostly congruent word BLUE) is presented as one dimension of a novel, transfer stimulus (e.g., GREEN in orange or BLUE in orange, respectively). Participants are faster to resolve interference when the mostly incongruent, item-specific feature is present, and therefore triggers a reduced reliance on the word.

A second theoretical implication of the present findings pertains to two viable computational models of item-specific control that have been developed recently (Blais et al., 2007; Verguts & Notebaert, 2008). To date, the available behavioral evidence has provided strong support for the contingency-learning hypothesis of ISPC effects in color–word Stroop (e.g., Schmidt & Besner, 2008, Reanalyses). In other words, an item-level control mechanism (e.g., conflict-monitoring, Blais et al.) has, until now, not been needed to account for ISPC effects in color–word Stroop. The novel evidence for item-specific control provided herein, and in particular the finding that item-specific control had a more pronounced influence on the incongruent trials, lends credence to the view that item-specific control of interference may be triggered by the occurrence of conflict, as these models posit. That the same pattern of a selective influence on incongruent relative to congruent trials is not consistently observed when context-specific control is used (Crump et al., 2006) yields important questions about the role of conflict in triggering control in CSPC relative to ISPC paradigms.[2] For example, it is possible that the contextual feature is detected and control adjustments triggered prior to the detection of conflict/word-related interference in some CSPC paradigms, producing an intermediary level of control that might be thought of as stimulus-triggered but relatively more proactive than item-specific control (cf. Bugg et al.'s, 2008 discussion of a CSPC effect based on font type). Should this difference be confirmed in subsequent work, it would further suggest a delineation of the context and item levels of control.

A third theoretical implication of the current findings is that they emphasize that not just any ISPC paradigm will yield a behavioral marker of reactive control. Rather, our findings identify several theoretically relevant factors that are important in producing control-based ISPC effects.

One such factor is the locus of the ISPC signal. When the relevant dimension signaled proportion congruency (Experiments 1 and 2), the ISPC effects that emerged reflected item-specific control. This is consistent with the item-specific control account (Bugg, Jacoby, et al., 2011). A second, previously unidentified factor is set-size. Consistent with our predictions, item-specific control dominated for the larger 4-item set size, whereas contingency learning dominated for the smaller 2-item set size (Experiment 3). This converges with other reports in the literature of the emergence of control mechanisms (as opposed to exclusive reliance on mechanisms such as repetition priming) with increases in set size (e.g., Bugg, 2008). In the ISPC paradigm, we believe that reliance on control in the 4-item set size reflects that, although there are high-contingency congruent responses, there are no high-contingency incongruent responses. In other words, on the most challenging trial type, contingency learning is not an effective means by which to select a response, but control is effective. This contrasts with the smaller, 2-item set size, where high-contingency incongruent (and congruent) responses exist, and reliance on contingency learning not only provides a reliable means of predicting the correct response, but may also permit participants to shortcut some processing when prediction is accurate (Schmidt & Besner, 2008). Set size is just one approach to manipulating the reliability of contingency learning (i.e., response-prediction processes), and future studies might attempt to implement other manipulations that may also yield reliance on item-specific control, as well as tease apart the contributions of such manipulations (including set size) and the reliability of contingency learning.

Although the current findings are largely consistent with the item-specific control account (Bugg, Jacoby, et al., 2011), one aspect of the current findings does suggest modification of the account. According to the account, contingency learning should dominate when the word is the ISPC signal. This appears to be an overly simplified view in light of the finding that item-specific control was operative in the 4-item set condition in Experiment 3. That is, in Experiment 3, words were the signal of proportion congruency (i.e., assigned to be mostly congruent or mostly in-

[2] Simple effects of context-specific proportion congruence for congruent and incongruent trials were not reported in Crump et al. (2006). However, eyeballing of the mean differences for congruent vs. incongruent trials, respectively, supports our conclusion: 3 vs. 12 ms (Crump et al., Exp 1), 12 vs. 13 ms (Crump et al., Exp 2a).

congruent) in both set-size conditions. Yet, the contribution of contingency learning was apparent only in the 2-item set condition. There are, however, several important differences between the 4-item set condition of the current Experiment 3 and Bugg, Jacoby, et al.'s third experiment, in which the ISPC signal was the word and contingency learning was dominant. One is that the current Experiment 3 utilized the nonoverlapping sets design, whereas Bugg, Jacoby, et al. used an overlapping sets design, and somewhat different mechanisms may be at play in each. More importantly, perhaps, is that Bugg, Jacoby, et al. used 2-item (word) sets in their experiment, with each word appearing with four possible pictures. Thus, their procedure may be more similar to our 2-item set than our 4-item set condition. Regardless of the exact locus, the differing patterns of findings across experiments suggest an update to the item-specific control account in recognizing that contingency learning mechanisms do not always dominate when the irrelevant dimension (i.e., word) is the ISPC signal; rather, use of contingency learning is further moderated by the size of the stimulus set.

General Conclusions and Future Directions

It is well established that humans detect and use correlations between words and colors in the Stroop task to optimize performance (e.g., Algom et al., 1996; Dishon-Berkovits & Algom, 2000; Melara & Algom, 2003; Sabri et al., 2001). The current set of experiments confirms use of these correlations, and expands the correlation account by refining our understanding of the conditions under which the correlations are used as a basis for item-specific control, as opposed to contingency learning. Although some ISPC effects are driven almost entirely by prediction of high-contingency responses via contingency learning (Schmidt & Besner, 2008, Reanalyses; Bugg, Jacoby, et al., 2011, Experiment 3), the mounting evidence, including the novel findings presented herein, suggests that the contribution of contingency learning to ISPC effects is limited. In other words, use of the correlations between colors and words is not restricted to contingency learning. Rather, item-specific control is a dominant mechanism that underlies ISPC effects in the color–word Stroop task (see Bugg, Jacoby, et al., 2011 for evidence with picture–word Stroop), with this mechanism reflecting individuals' use of the information that the correlations between colors and words conveys regarding proportion congruency.

We have shown that preferential use of contingency learning in the color–word Stroop task appears specific to methodologies in which there is a high-contingency incongruent response, such as the use of 2-item nonoverlapping sets. Use of other methodologies in which set size is increased indicates that item-specific control is dominant. Arguably, it is more common in Stroop paradigms found across the literature to use more than a single incongruent color for each item (e.g., Dishon-Berkovits & Algom, 2000; Stroop, 1935). For instance, a paradigm with four words and four colors would have three equally frequent incongruent responses to each item. Given the present 4-item results, it is likely that item-specific inhibition dominates under such conditions in which no high-contingency incongruent response exists. One must be cautious not to overgeneralize use of item-specific control (or contingency learning), however. Such mechanisms would seemingly not be implemented in some Stroop tasks, such as those that employ a 2 (color) × 2 (word) 50% congruent design, where no correlation exists between words and colors. As demonstrated by Algom and colleagues (Dishon-Berkovits & Algom, 2000; Melara & Algom, 2003), no Stroop interference occurs in this case, which suggests that words are not always automatically read and hence their influence need not always be controlled.

With the knowledge afforded by the current findings in hand, one can begin to explore whether item-specific contingency learning and item-specific control can be further dissociated, for instance by examining individual or group differences that may selectively influence one versus the other mechanism. As an example, older adults have been shown to demonstrate ISPC effects (Bugg et al., 2008). This finding is somewhat surprising in light of the notion that cognitive control declines with age (e.g., Hasher & Zacks, 1988; but see Verhaeghen, 2011). It is less surprising, however, if one considers the fact that the ISPC effect for older adults emerged from a design that utilized a 2-item set, the design shown here to promote reliance on contingency learning. The appropriate interpretation may then be that older adults show intact, simple, stimulus-response learning, and not maintenance of reactive control.

Similarly, Hutchison (2011) recently obtained larger ISPC effects in error rates from low working-memory capacity (WMC) individuals than high-WMC individuals. Hutchison argued that ISPC effects increase in the absence of proactive control. In other words, if the word is not suppressed, then it is more available to associate with contingent responses. High-WMC individual's greater use of proactive control was also used to explain why they did not show list-based proportion congruence effects, whereas low-WMC individuals did. Presumably, if high-WMC individuals use proactive control from the start, then they are not dependent on the "support" that mostly incongruent lists provide. Thus, low-WMC individuals, like older adults, might show intact simple stimulus-response learning, but impaired control. Contrasting ISPC effects in a 2-item and 4-item set condition for those with low-WMC and older adults appears a fruitful approach for determining whether individuals in these groups can engage item-specific control.

At a more general level, our findings contribute to the broader literature on attention and cognitive control by revealing that human performance is enhanced when participants can make use of existing correlations present in the environment (Melara & Algom, 2003). Our study demonstrates that such use includes access to information regarding the overall likelihood of interference, as well as any associations between stimuli and particular responses. Our results also show that enhancing performance in situations that involve attentional conflict (e.g., distractors) does not solely depend upon advance use of such information in a proactive or preparatory fashion (e.g., as in the case of list-level control). That is, in our paradigms, participants cannot know whether an upcoming item is associated with a high (mostly incongruent) or low (mostly congruent) likelihood of interference until the item is presented. Still, converging evidence across three experiments indicated a highly flexible and fast-acting deployment of cognitive control that occurs after the onset of the item. This evidence for item-specific control suggests a broadening of previous definitions of cognitive control that focused exclusively on proactive or preparatory mechanisms (e.g., Posner & Snyder, 1975; Shiffrin & Schneider, 1977) to include reactive mechanisms, consistent with the dual-mechanisms-of-control account (Braver et al., 2007). Perhaps most importantly, our evidence for item-specific control in ISPC effects suggests that the presentation of a particular item can trigger not only retrieval of responses that have been previously linked with a particular item, but also retrieval of more abstract attentional control settings that have been previously applied to the item.

This view of stimulus-driven control is consistent with selective attention theories, which argue that people encode and later remember that distracting stimuli are *to be ignored* (Neill, Valdes, & Terry, 1995; Tipper, 2001). However, those theories focused only on the fate of retrieved items themselves. Thus, although such theories can explain the item-specific control effects found for words in Experiment 3, they would need modification to explain the color-specific control effects of Experiments 1 and 2 (including transfer) or the picture-specific effects of Bugg, Jacoby, et al. (2011), in which retrieval of one item causes suppression of another. One possibility is that event files are encoded (Hommel, 2003), and on incongruent trials these files include not only the specific words and colors, but the conflict experienced and the subsequent need to suppress word reading. Future retrieval of either the words or colors (or other contextual features such as font or location) from a previous incongruent trial could automatically reinstate word suppression. As stated previously, such suppression could take the form of a shape-based, word-reading filter in which attention is directed away from shapes representing general word forms. Alternatively, the frequent conflict associated with mostly incongruent colors could lead to more efficient response selection on future conflict trials through retrieval of past conflict episodes involving the color, which may include how such conflict was resolved in favor of the color name itself. Future research will hopefully investigate more thoroughly the exact mechanisms involved in learning such color-based reactive control.

In conclusion, the current paper adds to our conceptualization of cognitive control by providing evidence for an item-specific, reactive control mechanism that is separate from any specific stimulus–response contingency learning. These results lend support to Braver and colleagues' (2007) dual-mechanisms-of-control theory. This theory allows for both the classic conceptualizations of slow, effortful, and voluntary preparatory control as well as the faster and more flexible stimulus-driven, reactive control mechanisms evidenced in the current paper.

References

Algom, D., Dekel, A., & Pansky, A. (1996). The perception of number from the separability of the stimulus: The Stroop effect revisited. *Memory & Cognition, 24,* 557–572. doi:10.3758/BF03201083

Blais, C., & Bunge, S. (2010). Behavioral and neural evidence for item-specific performance monitoring. *Journal of Cognitive Neuroscience, 22,* 2758–2767. doi:10.1162/jocn.2009.21365

Blais, C., Robidoux, S., Risko, E. F., & Besner, D. (2007). Item-specific adaptation and the conflict monitoring hypothesis: A computational model. *Psychological Review, 114,* 1076–1086. doi:10.1037/0033-295X.114.4.1076

Botvinick, M. M., Braver, T. S., Barch, D. M., Carter, C. S., & Cohen, J. D. (2001). Conflict monitoring and cognitive control. *Psychological Review, 108,* 624–652. doi:10.1037/0033-295X.108.3.624

Braver, T. S., Gray, J. R., & Burgess, G. C. (2007). Explaining the many varieties of working memory variation: Dual mechanisms of cognitive control. In A. R. A. Conway, C. Jarrold, M. J. Kane, A. Miyake, & J. N. Towse (Eds.), *Variation in working memory* (pp. 76–106). New York, NY: Oxford University Press.

Bugg, J. M. (2008). Opposing influences on conflict-driven adaptation in the Eriksen flanker task. *Memory & Cognition, 36,* 1217–1227. doi:10.3758/MC.36.7.1217

Bugg, J. M., & Chanani, S. (2011). List-wide control is not entirely elusive: Evidence from picture–word Stroop. *Psychonomic Bulletin & Review, 18,* 930–936. doi:10.3758/s13423-011-0112-y

Bugg, J. M., Jacoby, L. L., & Chanani, S. (2011). Why it is too early to lose control in accounts of item-specific proportion congruency effects? *Journal of Experimental Psychology: Human Perception and Performance, 37,* 844–859. doi:10.1037/a0019957

Bugg, J. M., Jacoby, L. L., & Toth, J. (2008). Multiple levels of control in the Stroop task. *Memory & Cognition, 36,* 1484–1494. doi:10.3758/MC.36.8.1484

Bugg, J. M., McDaniel, M. A., Scullin, M. K., & Braver, T. S. (2011). Revealing list-level control in the Stroop task by uncovering its benefits and a cost. *Journal of Experimental Psychology: Human Perception and Performance, 37,* 1595–1606. doi:10.1037/a0024670

Crump, M. J., Gong, Z., & Milliken, B. (2006). The context-specific, proportion-congruent Stroop effect: Location as a contextual cue. *Psychonomic Bulletin & Review, 13,* 316–321. doi:10.3758/BF03193850

Crump, M. J. C., & Milliken, B. (2009). The flexibility of context-specific control: Evidence for context-driven generalization of item-specific control. *Quarterly Journal of Experimental Psychology, 62,* 1523–1532. doi:10.1080/17470210902752096

Dell'Acqua, R., Job, R., Peressotti, F., & Pascali, A. (2007). The picture–word interference effect is not a Stroop effect. *Psychonomic Bulletin & Review, 14,* 717–722. doi:10.3758/BF03196827

Dishon-Berkovits, M., & Algom, D. (2000). The Stroop effect: It is not the robust phenomenon that you have thought it to be. *Memory & Cognition, 28,* 1437–1449. doi:10.3758/BF03211844

Hasher, L., & Zacks, R. T. (1988). Working memory, comprehension, and aging: A review and a new view. In G. H. Bower (Ed.), *The psychology of learning and motivation* (Vol. 22, pp. 193–225). San Diego, CA: Academic Press.

Hommel, B. (2003). Acquisition and control of voluntary action. In S. Maasen, W. Prinz, & G. Roth (Eds.), *Voluntary action: Brains, minds, and sociality* (pp. 34–48). Oxford: Oxford University Press.

Hutchison, K. A. (2011). The interactive effects of list-based control, item-based control, and working memory capacity on Stroop performance. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 37,* 851–860. doi:10.1037/a0023437

Jacoby, L. L., Lindsay, D. S., & Hessels, S. (2003). Item-specific control of automatic processes: Stroop process dissociations. *Psychonomic Bulletin & Review, 10*(3), 638–644. doi:10.3758/BF03196526

Jacoby, L. L., McElree, B., & Trainham, T. N. (1999). Automatic influences as accessibility bias in memory and Stroop tasks: Toward a formal model. In D. Gopher & A. Koriat (Eds.), *Attention and performance XVII: Cognitive regulation of performance: Interaction of theory and application* (pp. 461–486). Cambridge, MA: Bradford, MIT Press.

Leboe, L. C., & Mondor, T. A. (2007). Item-specific congruency effects in nonverbal auditory Stroop. *Psychological Research, 71,* 568–575. doi:10.1007/s00426-006-0049-3

Lindsay, D. S., & Jacoby, L. L. (1994). Stroop process dissociations: The relationship between facilitation and interference. *Journal of Experimental Psychology: Human Perception and Performance, 20,* 219–234. doi:10.1037/0096-1523.20.2.219

Logan, G. D. (1988). Toward an instance theory of automatization. *Psychological Review, 95,* 492–527. doi:10.1037/0033-295X.95.4.492

Logan, G. D., Zbrodoff, N. J., & Williamson, J. (1984). Strategies in the color–word Stroop task. *Bulletin of the Psychonomic Society, 22,* 135–138.

Lowe, D. G., & Mitterer, J. O. (1982). Selective and divided attention in a Stroop task. *Canadian Journal of Psychology, 36,* 684–700. doi:10.1037/h0080661

Melara, R. D., & Algom, D. (2003). Driven by information: A tectonic theory of Stroop effects. *Psychological Review, 110,* 422–471. doi:10.1037/0033-295X.110.3.422

Melara, R. D., & Mounts, J. R. W. (1993). Selective attention to Stroop dimensions: Effects of baseline discriminability, response mode, and practice. *Memory & Cognition, 21,* 627–645. doi:10.3758/BF03197195

Musen, G., & Squire, L. R. (1993). Implicit learning of color-word associations using a Stroop paradigm. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 19,* 789–798.

Neill, W. T., Valdes, L. A., & Terry, K. M. (1995). Selective attention and the inhibitory control of cognition. In F. N. Dempster & C. J. Brainerd (Eds.), *Interference and inhibition in cognition* (pp. 207–261). San Diego, CA: Academic Press. doi:10.1016/B978-012208930-5/50008-8

Posner, M. I., & Snyder, C. R. R. (1975). Attention and cognitive control. In R. L. Solso (Ed.), *Information processing and cognition: The Loyola Symposium* (pp. 55–85). Hillsdale, NJ: Erlbaum.

Sabri, M., Melara, R. D., & Algom, D. (2001). A confluence of contexts: Asymmetric versus global failures of selective attention to Stroop dimensions. *Journal of Experimental Psychology: Human Perception and Performance, 27,* 515–537. doi:10.1037/0096-1523.27.3.515

Schmidt, J. R., & Besner, D. (2008). The Stroop effect: Why proportion congruence has nothing to do with congruency and everything to do with contingency. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 34,* 514–523. doi:10.1037/0278-7393.34.3.514

Schneider, W., Eschman, A., & Zuccolotto, A. (2002). *E-Prime reference guide.* Pittsburgh, PA: Psychology Software Tools.

Shiffrin, R. M., & Schneider, W. (1977). Controlled and automatic human information processing: II. Perceptual learning, automatic attending, and a general theory. *Psychological Review, 84,* 127–190.

Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology, 18,* 643–662. doi:10.1037/h0054651

Tipper, S. P. (2001). Does negative priming reflect inhibitory mechanisms? A review and integration of conflicting views. *The Quarterly Journal of Experimental Psychology: A. Human Experimental Psychology, 54,* 321–343. doi:10.1080/02724980042000183

Van Maanen, L., Van Rijn, H., & Borst, J. P. (2009). Stroop and picture–word interference are two sides of the same coin. *Psychonomic Bulletin & Review, 16,* 987–999. doi:10.3758/PBR.16.6.987

Verguts, T., & Notebaert, W. (2008). Hebbian learning of cognitive control: Dealing with specific and nonspecific adaptation. *Psychological Review, 115,* 518–525. doi:10.1037/0033-295X.115.2.518

Verhaeghen, P. (2011). Aging and executive control: Reports of a demise greatly exaggerated. *Current Directions in Psychological Science, 20,* 174–180. doi:10.1177/0963721411408772

Virzi, R. A., & Egeth, H. E. (1985). Toward a translational model of Stroop interference *Memory & Cognition, 13,* 304–319. doi:10.3758/BF03202499

Received December 13, 2011
Revision received April 17, 2012
Accepted May 22, 2012 ■