

# Why It Is too Early to Lose Control in Accounts of Item-Specific Proportion Congruency Effects

Julie M. Bugg, Larry L. Jacoby, and Swati Chanani  
Washington University in St. Louis

The item-specific proportion congruency (ISPC) effect is the finding of attenuated interference for mostly incongruent as compared to mostly congruent items. A debate in the Stroop literature concerns the mechanisms underlying this effect. Noting a confound between proportion congruency and contingency, Schmidt and Besner (2008) suggested that ISPC effects are entirely contingency based. We introduce a broader theoretical analysis that points to the contribution of both contingency and item-specific control mechanisms. Our analysis highlights that proportion congruency is not confounded with contingency when the relevant dimension functions as the ISPC signal, and predicts that evidence of item-specific control should be obtained by shifting the signal from the irrelevant to the relevant dimension. We examine this prediction in a picture-word Stroop paradigm. When the relevant dimension functions as the ISPC signal (Experiments 1 and 2), evidence of control is obtained. When the irrelevant dimension functions as the ISPC signal (Experiment 3), contingencies can account for the ISPC effect. These patterns support our theoretical analysis, challenge a pure contingency account, and favor the inclusion of control in accounts of ISPC effects.

*Keywords:* picture-word Stroop, item-specific proportion congruency, cognitive control, contingency learning

In the classic color-word Stroop task, participants name the color of ink in which words are printed (Stroop, 1935). Stroop interference refers to the increased reaction time for incongruent (e.g., *BLUE* written in red ink) as compared to congruent (e.g., *BLUE* written in blue ink) trials. Numerous studies have attempted to characterize the mechanisms used to resolve interference in this task (for review, see MacLeod, 1991). A particularly useful approach involves proportion congruence manipulations. For example, the use of list-wide proportion congruence manipulations, whereby the proportion of congruent relative to incongruent trials is varied across lists (i.e., blocks), has revealed that Stroop interference is attenuated when lists are composed mostly of incongruent trials (e.g., Logan & Zbrodoff, 1979; West & Baylis, 1998). This list-wide proportion congruence effect is commonly attributed to global (i.e., uniform) control strategies (e.g., attend to the color, Botvinick, Braver, Barch, Carter, & Cohen, 2001) that are implemented based on expectancies. When incongruent trials are expected, as in the mostly incongruent condition, less processing is afforded to word reading than in the mostly congruent condition (Lindsay & Jacoby, 1994). This list-wide mechanism contrasts with a second interference-resolution mechanism that has been revealed via an item-specific proportion congruence manipulation.

The item-specific manipulation is implemented by assigning words (i.e., items) to a mostly incongruent set (e.g., *BLUE & GREEN*) or a mostly congruent set (e.g., *YELLOW & WHITE*) and intermixing all words within a list (for a variation on this procedure involving auditory Stroop stimuli, see Leboe & Mondor, 2007). As such, the majority of the time the word *BLUE* occurs in green ink and occasionally in blue ink, whereas the word *YELLOW* occurs frequently in yellow ink, and occasionally in white ink. Stroop interference is attenuated for the mostly incongruent as compared to the mostly congruent set of items (i.e., item-specific proportion congruence (ISPC) effect; Jacoby, Lindsay, & Hessels, 2003). It is important to note that the ISPC effect is observed in a list-wide context that is 50% congruent and therefore a global control mechanism cannot account for this pattern. Rather, the effect has been attributed to local, item-specific mechanisms that respond rapidly, poststimulus onset to resolve interference. A current theoretical debate centers on the nature of these item-specific mechanisms.

One view is that interference is resolved via item-specific control. By this view (which we refer to as the *control account*), *control* refers to the action of a word-reading filter that flexibly modulates the degree to which the word influences response selection depending on the proportion congruency (e.g., mostly congruent vs. mostly incongruent) of an item (Jacoby et al., 2003). For example, on identification of an item (i.e., word) as mostly incongruent, the word-reading filter quickly dampens activation of the irrelevant word dimension. A primary challenge to the item-specific control account is that it suggests the decision to not attend (or to attend) to the word occurs after a word is already read (Schmidt & Besner, 2008). A recent demonstration of a font-specific proportion congruence effect (i.e., less interference for words presented in a mostly incongruent font type, Bugg, Jacoby, & Toth, 2008) may, however, alleviate this concern. When proportion congruency is manipulated by changing the font type used

---

This article was published Online First August 16, 2010.

Julie M. Bugg, Larry L. Jacoby, and Swati Chanani, Department of Psychology, Washington University in St. Louis.

This research was supported by National Institute on Aging Grant 5T32AG00030. Portions of the data were presented at the 49th annual meeting of the Psychonomic Society, Chicago, IL. We are grateful to Jacqueline Greb and Aurora Willgren for assistance with data collection.

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

to print the word stimuli, changes in the shape of the words accompany this manipulation. As suggested by Bugg et al. (2008) shape may be a perceptual signal that is extracted prior to complete word reading and used to identify font-specific and possibly ISPC, and subsequently modulate control.

A second view focuses on a different mechanism that is proposed to mediate the ISPC effect; it involves associative (i.e., contingency) learning whereby participants learn to predict the response that is most frequently associated with a given stimulus (Jacoby et al., 2003). Following from the example above, participants would quickly respond “green” when the word *BLUE* is presented and “yellow” when the word *YELLOW* is presented because these are the most frequently encountered stimulus-response pairings. Indeed, associative learning plays a prominent role in several theoretical accounts of Stroop interference in tasks in which the relevant and irrelevant dimensions are correlated and the distracting word is therefore predictive of the identity of the target dimension (Dishon-Berkovits & Algom, 2000; Melara & Algom, 2003). Most notably for present purposes, the recently proposed contingency account (Schmidt & Besner, 2008) challenges the notion that item-specific control (i.e., proportion congruency dependent modulation of word reading) plays any role in ISPC effects.<sup>1</sup> The contingency account posits that proportion congruency effects in the Stroop task, including the ISPC effect, have nothing to do with proportion congruency per se but instead are confounded with contingency and can therefore be accounted for entirely by stimulus-response learning.

A primary piece of evidence in support of the contingency account stems from a reanalysis of data from Jacoby et al. (2003). Rearranging the critical cells to de-confound proportion congruency and contingency, Schmidt and Besner (2008) compared high contingency trials (e.g., mostly congruent-congruent vs. mostly incongruent-incongruent), medium contingency trials (e.g., 50% congruent vs. 50% incongruent), and low contingency trials (e.g., mostly incongruent-congruent vs. mostly congruent-incongruent). Consistent with the predictions of the contingency account, main effects of trial type and contingency were observed. Response times were facilitated for the high contingency trials. Most critical, there was no interaction between trial type and contingency, a finding which, according to Schmidt and Besner, was inconsistent with an account that emphasizes modulation of word reading because “incongruent trials should be more affected by attention, given that the majority of the Stroop effect is interference with little or no facilitation from congruent trials” (p. 516).

As for errors, the reanalysis again demonstrated main effects of trial type and contingency, but no interaction. In contrast to the response time data, both a facilitative effect of contingency on error rate for the high contingency trials and an interfering effect for the low contingency trials were found. These patterns are consistent with a response threshold mechanism that uses information about the predictability of words (i.e., contingency) to decrease the threshold for the predicted response on a high contingency trial while leaving the threshold for all other colors unchanged (Schmidt & Besner, 2008). Because the predicted (and lower threshold) response on the high contingency trial is the incorrect response on the corresponding low contingency trial, errors (interference) are more likely on low contingency trials.

The contingency account appears to provide a parsimonious explanation of ISPC effects, and proponents of this account may

therefore believe that it is time to abandon the notion that ISPC effects have something to do with control (cf. Schmidt & Besner, 2008). We, however, think that it may be too early to dismiss the contribution of control (i.e., the proportion congruency dependent modulation of word reading) to ISPC effects. To address this key issue, we develop a broader theoretical analysis of ISPC effects. To preface, our analysis highlights the absence of a confound between contingency and proportion congruency when the relevant dimension functions as the signal of ISPC. Our analysis, further, predicts that evidence of control may be obtained by biasing participants toward use of the relevant dimension as the ISPC signal. We conduct three experiments to provide an initial test of our account, paying special attention to performance on the incongruent trials when evaluating the effects of shifting the ISPC signal from the relevant (Experiments 1 and 2) to the irrelevant (Experiment 3) dimension. As has been noted, any modulation of word reading (i.e., control) that is operative within a given experimental context should disproportionately influence performance on the incongruent trials (Schmidt & Besner, 2008).

### A Broader Theoretical Analysis of ISPC Effects

One commonality of the item-specific control and contingency accounts is the assumption that the word dimension acts as the signal that directs subsequent processing. The control account posits that the word signals the ISPC associated with particular items and thereby directs modulation of word reading. This assumption is supported by evidence from the process-dissociation procedure that yielded higher word reading estimates for mostly congruent as compared to mostly incongruent items, but equivalent color-naming estimates as a function of item-specific proportion congruency (Jacoby et al., 2003). If the color-word combination or the color alone functioned as the signal of proportion congruency, then differences in the color-naming estimates should have been found. Based on the findings of the process-dissociation procedure, Jacoby et al. (2003) also reasoned that any stimulus-response associations that are acquired via exposure to the ISPC manipulation must be independent of the color. According to the contingency account posited by Schmidt and Besner (2008), the word acts as the signal of the stimulus-response contingencies that are associated with particular items and directs production of the response that is most frequently paired with a particular item (i.e., the word does not signal any information about proportion congruency per se). The contingency account simply emphasizes the degree to which responses can be predicted on the basis of the word (be it a color word: Re-analyses 1 & 2; or color-unrelated word: Experiments 1 & 2).

The convergence of the item-specific control and contingency accounts on this theoretical issue (i.e., which dimension is functioning as the critical signal that directs subsequent processing) is notable because the ISPC manipulation produces conditional prob-

<sup>1</sup> Note that Schmidt & Besner (2008) did refer to the shortcutting in responding that the contingency mechanism produces for certain conditions as “implicit control.” This should not be confused or equated with the control mechanism that is central to the item-specific control account, which may or may not be implicit in nature. Only the mechanism that is proposed in the item-specific control account modulates Stroop interference (based on the proportion congruency of particular items).

abilities of the color given the word and the word given the color that are identical for the most commonly instantiated ISPC manipulation involving two-item sets (Jacoby et al., 2003, Experiments 2a, 2b, 3; Schmidt & Besner, 2008, Re-analyses 1 & 2; see also Bugg et al., 2008, Experiment 1). This means that the word and the color are on equal footing with regard to the degree to which they are predictive of the ISPC associated with particular items. This raises two, theoretically important questions: (1) Why, in past studies, has there been a bias toward reliance on the word as the ISPC signal, and (2) could this bias explain the preferential use of contingency learning mechanisms as opposed to control in the ISPC paradigm?

### Reliance on Words as Signals

Beginning with the first question, we posit that the bias toward reliance on the word may depend heavily on a key structure within Melara and Algom's (2003) tectonic theory, dimensional imbalance. *Dimensional imbalance* refers to the efficiency with which dimensions (e.g., words vs. ink colors) can be accessed in long-term memory, with the degree of dimensional imbalance reflecting changes in both the psychophysical (i.e., physical differences between stimulus values that impact their discriminability) and production (i.e., response mode) contexts (Melara & Algom, 2003). For present purposes, the key point is that there is little doubt that the dimensional imbalance in previous investigations of the ISPC effect (e.g., Jacoby et al., 2003; Schmidt & Besner, 2008; see also Bugg et al., 2008, Experiment 1) favored discrimination of and access to the word dimension, and accordingly use of any information the words provided regarding proportion congruency or contingency. For example, with regard to the psychophysical context, previous studies presented color-word stimuli with the onset of each dimension occurring simultaneously. Words are at an advantage with such a procedure because they are read more quickly than colors are named (Melara & Algom, 2003; see also Fraise, 1969). In addition, previous studies presented the words at an optimal viewing angle and the production context mandated use of voice responses, both of which have been shown to favor processing of words (Melara & Mounts, 1993; Virzi & Egeth, 1985).

### Using Signals to Produce Associated Responses Versus to Guide Control

Turning to the second question, we posit that the mechanisms underlying the ISPC effect may be closely tied to the dimension that is relied on as the ISPC signal. As highlighted by Schmidt and Besner (2008), proportion congruency manipulations are confounded with contingency when the word is functioning as the ISPC signal. Due to this confounding, participants can either modulate word reading depending on the proportion congruency of particular items (i.e., minimize interference for mostly incongruent items) or produce the response most frequently associated with particular words to produce the ISPC pattern. When the experimental context triggers reliance on the word as the ISPC signal, we hypothesize that the dominant approach will be one that involves production of responses associated with particular words (i.e., contingency learning mechanisms acquire the stimulus-response (S-R) contingencies that are confounded with proportion congru-

ency). Our reasoning is two fold. First, such a strategy (which is likely implicit; Musen & Squire, 1993; Schmidt, Crump, Cheesman, & Besner, 2007) mirrors the temporal processing dynamics pertaining to the degree of dimensional imbalance within such a context; that which is processed initially (i.e., the word) readily functions as the stimulus in the S-R chain. Second, the availability of such a strategy "allows participants to shortcut some processing when the predicted response is the correct one" (Schmidt & Besner, 2008, p. 515). The data from Jacoby et al. (2003) illustrate the rapid manner in which ISPC effects are observed. Robust differences in interference between mostly congruent and mostly incongruent items are found within just 16 trials. If these differences are driven by contingencies, as Schmidt and Besner's (2008) reanalysis of Jacoby et al. suggested, one must assume that the S (i.e., word) -R contingencies are acquired incredibly fast. Thus, almost as soon as the task begins, participants can shortcut processing and still rapidly produce the correct response on ~75% of the trials using associative-retrieval processes that are driven by attention to the word dimension.

In contrast, when the experimental context triggers reliance on the relevant dimension (e.g., the color) as the ISPC signal, we hypothesize that the dominant approach will be one that involves use of control to modulate Stroop interference. Note that this is a critical departure from a pure contingency account. The primary basis for this prediction relates to the fact that proportion congruency manipulations are not confounded with contingency when the relevant dimension is functioning as the ISPC signal. As shown in Table 1, utilization of the relevant dimension to predict the response leads to equivalent contingency levels for all possible combinations of proportion congruency and congruency. This is because the relevant dimension is the to-be-named dimension and therefore, 100% of the time the correct response correlates perfectly with the value of the relevant dimension. Thus, any observed differences in interference between mostly congruent and mostly incongruent items cannot be driven by contingencies. Instead, any differences may reflect use of the relevant dimension to modulate control depending on the proportion congruency of particular items.

One approach to testing this prediction is to shift participants' attention toward evaluating the informational value of the relevant dimension, and in particular its ability to predict proportion congruency. The approach we take to induce this shift and test the predictions that stem from our broader theoretical analysis is to implement an ISPC manipulation in a novel, picture-word Stroop paradigm in which participants are asked to name pictures. We chose picture-word Stroop because it offers a great deal of flexibility in manipulating dimensional imbalance (e.g., one can readily manipulate the ease with which words can be discriminated from the background pictures, vary the number of stimuli used to represent the relevant dimension, etc.), which according to our analysis strongly impacts attention toward and reliance on particular dimensions as ISPC signals (see Melara & Algom, 2003). In our picture-word analog, similar to color-word ISPC studies, participants view bidimensional stimuli and are always asked to name the picture and ignore the word (which is superimposed on the picture). We chose to use words and pictures from the same semantic category rather than unrelated words and pictures to ensure that Stroop interference would be robust (Costa, Alario, & Caramazza, 2005; Glaser, & Dungenhoff, 1984; Glaser & Glaser,

Table 1  
*Contingencies Between the Irrelevant or Relevant Dimension and Responses as a Function of Proportion Congruency and Congruency*

Signal	Congruency	Proportion congruency	
		High	Low
Irrelevant dimension	Congruent	High (0.75) contingency	Low (0.25) contingency
	Incongruent	Low (0.25) contingency	High (0.75) contingency
Relevant dimension	Congruent	High (1.0) contingency	High (1.0) contingency
	Incongruent	High (1.0) contingency	High (1.0) contingency

1989; La Heij, 1988; Lupker, 1979) such that the potential existed for item-specific proportion congruence effects to be observed.

The principle deviations from previous color-word ISPC studies involve alterations of the psychophysical and set size contexts, which are intended to shift attention toward the relevant (picture) dimension. Psychophysically speaking, we assumed that printing words in a font size that is disproportionately smaller than the size of the picture (Theios & Amrhein, 1989), using pictures that were relatively detailed to reduce the “pop-out” of the words, and ensuring that the words did not appear in the same location on screen across trials (see Figure 1 for sample stimuli) would increase the salience of the picture dimension and reduce the discriminability of the word. With regard to the set size context (i.e., number of stimulus values), whereas a set size of 16 is used for the picture dimension (four different pictures [i.e., exemplars] of each type of animal; see Figure 1 for an example), a disproportionately smaller set size of four is used for the word dimension. (In previous color-word ISPC studies, the set size associated with the color and word dimensions was equivalent.) As shown by Melara and Algom (2003), the set size context influences dimensional uncertainty, and in particular “surprisingness” which refers to the predictability of either the target or distracter’s appearance. The more uncertain it is that a particular stimulus (i.e., target or distracter) will appear, the more surprising it is when it does and the greater the informational value of the stimulus. We therefore assumed that our manipulation of set size context would boost the surprisingness of the relevant, picture dimension.

Given the interactive nature of structures within tectonic theory, we assumed that the psychophysical and set size manipulations together would decrease the difference between the time required to access the word dimension and the relevant dimension (i.e., dimensional imbalance) and shift attention toward processing the informational value of the relevant picture dimension (due to its surprisingness). Although the word is expected to continue to gain access to the response system (because dimensional imbalance is shifted but not reversed), the proposed contextual changes should open the door for item-specific control adjustments, as triggered by the pictures. Such adjustments are expected to modulate the influence of the word on selection of the appropriate response (and the magnitude of resultant interference effects). A mostly incongruent picture, for example, should trigger reduced processing of and reliance on the word relative to a mostly congruent picture.

### Experiment 1

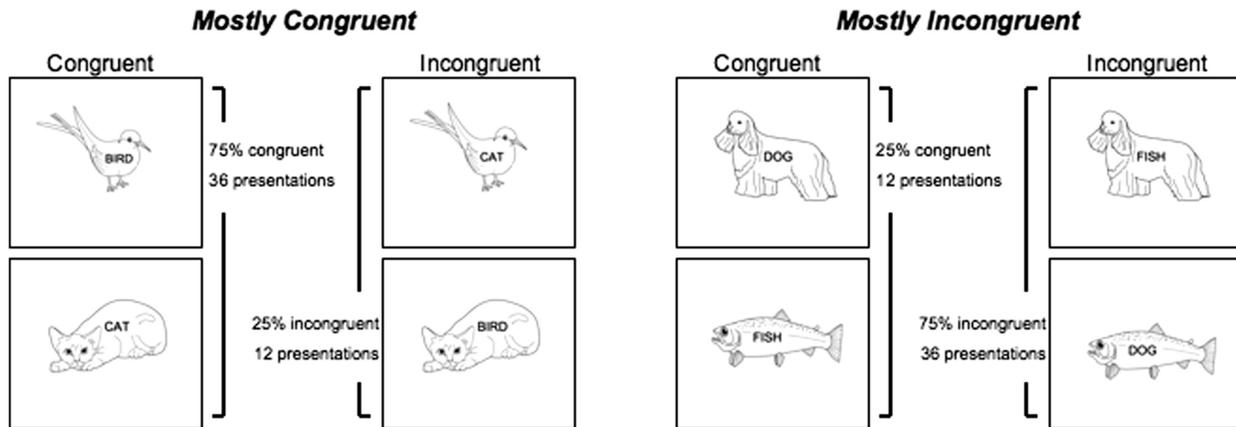
In Experiment 1, we present an initial test of our theoretical account of ISPC effects by attempting to tip the scales in favor of

use of the relevant dimension as a signal of proportion congruency and corresponding control adjustments. Keeping with previous examinations of ISPC effects in the color-word Stroop task (e.g., Bugg et al., 2008, Experiment 1; Jacoby et al., 2003, Experiments 2a, 2b, & 3), four different words (*BIRD*, *CAT*, *DOG*, and *FISH*) were used with two of the words (e.g., *BIRD* and *CAT*) assigned to a mostly congruent set and two of the words (e.g., *FISH* and *DOG*) assigned to a mostly incongruent set. These items are referred to as training stimuli (see Figure 1). In addition, as in previous studies, the sets were not permitted to overlap (i.e., the word *BIRD* was not superimposed on a picture of a fish or dog). As such, the conditional probabilities of the picture given the word and vice versa were equivalent. Words and pictures were therefore equally predictive of the proportion congruency of particular items; as noted above, however, only the ISPC of the words but not the pictures was confounded with contingency. Participants were instructed to name the animal in the picture and, as in previous studies, there were four possible naming responses (“bird,” “cat,” “dog,” or “fish”) to the relevant stimuli, and these responses overlapped with the words.

The principle deviations from previous color-word ISPC studies involved the systematic alterations of the psychophysical and set size contexts, as noted above. An additional deviation from previous color-word ISPC studies was the inclusion of trials in which transfer stimuli were presented (see Figure 1). The transfer trials appeared only in a third block and were intermixed with the training trials that appeared during the first two blocks. Transfer trials were included to gain traction on whether the aforementioned changes shifted the signal to the picture dimension. The transfer trials consisted of old words superimposed atop new pictures of birds, cats, dogs, and fish that were not encountered during training. Both congruent trials (e.g., *BIRD* atop a new picture of a bird), and incongruent trials that were of a “near” or “far” nature (defined below) were included so that the transfer stimuli would be frequency unbiased (i.e., 50% congruent and 50% incongruent).

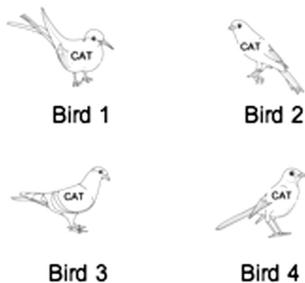
The congruent (e.g., *CAT* atop a new picture of a cat) and near transfer incongruent stimuli were composed of a picture/word pairing encountered previously (e.g., *CAT* atop a new picture of a bird, or *FISH* atop a new picture of a dog). As shown in Figure 1, the animal designated by the word and the animal designated by the picture signal the same control adjustment or the same associated response, and therefore disentangling the contributions of the picture and word signals is not possible on these trials. Therefore, these trials were not analyzed. The critical trial type was the far transfer incongruent stimuli that were composed of a picture/word pairing not encountered previously (e.g., *FISH* atop a new picture of a bird, or *CAT* atop a new

## Experiment 1: TRAINING STIMULI



### Example of set size manipulation:

#### Training stimuli



## Experiment 1: TRANSFER STIMULI (50% Congruent)

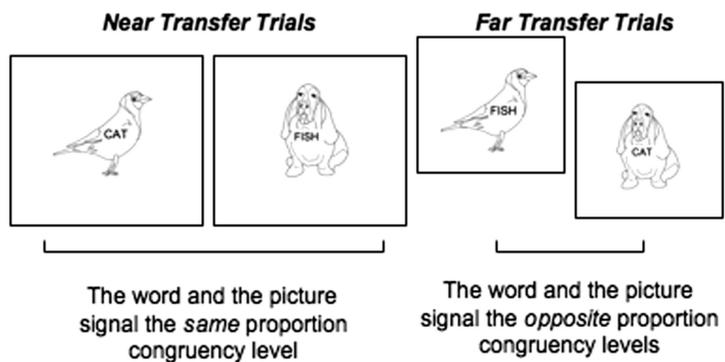


Figure 1. Sample picture-word Stroop stimuli and the nonoverlapping sets design of Experiment 1. Original images are from TheColoringSpot.com

picture of a dog). On these trials, as shown in Figure 1, the word and picture signals are in opposition. That is, during training trials the word (e.g., *CAT*) is assigned to one level of proportion congruence while the animal category represented by the picture (e.g., dog) is assigned to the opposite level. Comparing response times on trials in which words from the mostly congruent training set are paired with a picture from an animal category in the mostly incongruent training set and vice versa permits one to examine the degree to which the word versus picture is functioning as the signal of proportion congruency or contingency and guiding responding.

Our predictions were as follows. First, we hypothesized that an ISPC effect would be obtained for the training trials in the picture-word task with Stroop interference being larger for the mostly congruent as compared to the mostly incongruent items. This prediction was confirmed. Second, following from our theoretical analysis, we assumed that the psychophysical and set size contexts would shift dimensional imbalance away from the word and augment reliance on the picture such that the picture would be used as the signal of proportion congruency and corresponding adjustments in control. We tested this prediction in two steps. First, we conducted the contingency analysis on the training trials that was forwarded by Schmidt and Besner (2008). If the contingency account universally explains

ISPC effects, then this analysis should show main effects of trial type and contingency but no interaction between these factors. Alternatively, if item-specific control now plays a role, then the interaction should also be obtained. The results of the contingency analysis indicated that the ISPC effect we obtain is not readily explained by the contingency account but instead is captured by a control account (as indicated by the disproportionate influence of the ISPC manipulation on the incongruent trials). According to our theoretical analysis, this is precisely the finding one would expect if the picture, rather than the word, is functioning as the more potent signal of proportion congruency in the present picture-word paradigm. To gain converging support for this conclusion, we examined performance on the far transfer trials, and predicted that responding would be faster and more accurate on trials in which a mostly incongruent picture is paired with a mostly congruent word as compared to trials in which a mostly incongruent word is paired with a mostly congruent picture.

## Method

**Participants.** There were 20 undergraduates (seven men, 13 women) aged 18 to 22 years at Washington University in St. Louis who participated for course credit or \$10. All participants provided

informed consent, and were native English speakers with normal or corrected vision.

**Materials and design.** Twenty-eight black and white line drawings (seven cats, dogs, birds, and fish) were obtained from <http://thecoloringspot.com> and used as picture stimuli. The artist granted the experimenters permission to use the pictures for experimental purposes. The pictures were modified to remove excessive details using PhotoShop. PowerPoint was used to approximately equate the size of the pictures and to superimpose the words on the picture stimuli (see Figure 1 for sample stimuli).

A 2 (trial type: congruent vs. incongruent)  $\times$  2 (proportion congruence: mostly congruent vs. mostly incongruent)  $\times$  2 (training vs. transfer) within-subjects design was implemented. As shown in Table 2, four animal words were divided into two pairs (*BIRD* and *CAT*, *DOG* and *FISH*), and words from one pair (e.g., *BIRD* and *CAT*) were assigned to the mostly congruent set while words from the other pair (e.g., *DOG* and *FISH*) were assigned to the mostly incongruent set. Assignment of pairs to the mostly congruent or incongruent set was counterbalanced across participants. Four pictures of each animal were used to create the training stimuli. Within each of the first two training blocks, a word assigned to the mostly congruent set (e.g., *BIRD*) was presented nine times with each of the four congruent pictures (e.g., birds), and three times with each of the four incongruent pictures (e.g., cats). A word assigned to the mostly incongruent set (e.g., *DOG*) was presented three times with each of the four congruent pictures, and nine times with each of the four incongruent pictures (e.g., fish). As such, the conditional probability of the picture given the word was identical to the conditional probability of the word given the picture.<sup>2</sup> The mostly congruent and mostly incongruent sets were mixed during presentation such that the list-wide proportion

congruence was 50%. Sixteen neutral stimuli were also presented during the first two blocks and were identical to the training stimuli but consisted of the picture without a word. The neutral stimuli were included to ensure that the naming times were similar for pictures in the mostly congruent and mostly incongruent sets.

Three pictures of each animal, which were different from the training pictures, were used to create the transfer stimuli. Within the transfer block, each of these pictures was presented three times as a congruent item (three times with the congruent word) and three times as an incongruent item (once with each of the three incongruent words). Thus the proportion congruency of these items was 50%. The near transfer incongruent trials were those that entailed a picture/word pairing encountered during training (e.g., the word *CAT* superimposed on one of the new pictures of a bird). The far transfer incongruent trials were those that entailed a picture/word pairing not encountered during training (e.g., the word *CAT* superimposed on one of the new pictures of a dog).

**Procedure.** Participants were seated in a small room with the experimenter present. E-prime (Psychological Software Tools, Pittsburgh, PA) was used for stimulus presentation and data recording. Participants were instructed to name aloud the animal in the picture as quickly as possible while maintaining a high level of accuracy. Participants were instructed to use the general category label for each animal (i.e., bird, cat, dog, or fish) rather than more specific labels (e.g., robin) when responding. After completing 20 practice trials, participants performed three blocks of trials, with a short break between blocks. Each of the first two blocks consisted of 208 stimuli and was composed entirely of training stimuli. In the third block, referred to as the transfer phase, 216 stimuli were presented. These included the training stimuli that continued to be presented in accordance with their assignment to the mostly congruent (75% congruent) or mostly incongruent (25% congruent) sets, and the transfer stimuli. On each trial within a block, the stimulus was presented in the center of the screen within an invisible frame that was approximately 10"  $\times$  10". The pictures subtended approximately 20° visual angle, whereas the word subtended approximately 5° visual angle. The stimulus remained onscreen until a voice response was detected. The experimenter then keyed in the participant's response, and the next stimulus was presented 1 s later. Trials on which the voice key was tripped by imperceptible speech or extraneous noise were coded as scratch trials. Reaction time (RT) and error rate were recorded. The entire procedure lasted approximately 45 min.

## Results

For each participant, RTs less than 200 ms or greater than 3,000 ms were removed, which eliminated less than 1% of the trials. The alpha level was set at .05 for the following and all subsequent analyses reported herein. Partial eta-squared ( $\eta_p^2$ ) is reported as the measure of effect size. The analysis of RT for the neutral trials indicated that participants were equally fast at naming pictures from the mostly congruent ( $M = 636$ ) and mostly incongruent ( $M = 616$ ) conditions,  $t(19) = 1.51, p = .147$ .

Table 2  
Frequencies of Picture-Word Pairings for Each of the Training Blocks in Experiments 1, 2, and 3

Experiment	Word	Picture			
		Bird	Cat	Dog	Fish
1	<i>BIRD</i>	<u>36</u>	12	—	—
	<i>CAT</i>	12	<u>36</u>	—	—
	<i>DOG</i>	—	—	<u>12</u>	<u>36</u>
	<i>FISH</i>	—	—	<u>36</u>	<u>12</u>
2	<i>BIRD</i>	<u>36</u>	4	12	12
	<i>CAT</i>	4	<u>36</u>	12	12
	<i>DOG</i>	4	4	<u>12</u>	12
	<i>FISH</i>	4	4	12	<u>12</u>
3	<i>BIRD</i>	<u>36</u>	4	4	4
	<i>CAT</i>	4	<u>36</u>	4	4
	<i>DOG</i>	12	12	<u>12</u>	12
	<i>FISH</i>	12	12	12	<u>12</u>

*Note.* The underlined figures refer to congruent trials; a dash (—) refers to the absence of a particular picture/word pairing. A given frequency (e.g., the 36 that corresponds to the pairing of bird with the word *BIRD* in Experiment 1) was derived by collapsing across the four different pictures that were used to represent a particular animal category (i.e., each of the four birds was presented nine times with the word *BIRD*). Above frequencies refer to the version in which bird (or *BIRD*) and cat (or *CAT*) were assigned to be mostly congruent and dog (or *DOG*) and fish (or *FISH*) were mostly incongruent. As noted in the Method section, assignment was counterbalanced across participants.

<sup>2</sup> Given these conditional probabilities, it is reasonable to describe the assignment of items to mostly congruent and incongruent sets as being based on assignment of pictures rather than words. To be consistent with prior research, we refer to words being assigned to sets in Experiment 1.

**Analysis of proportion congruency: Training stimuli.** The mean RTs and error rate for congruent and incongruent trials are presented in Table 3. First, we analyzed RT and error rate on the training stimuli using separate  $2 \times 2$  repeated measures analyses of variance (ANOVAs) with trial type (congruent vs. incongruent) and proportion congruence (mostly congruent vs. mostly incongruent) as factors. For RT, significant Stroop interference was observed ( $M = 92$  ms) as indicated by the main effect of trial type,  $F(1, 19) = 192.29$ ,  $MSE = 880.30$ ,  $p < .001$ ,  $\eta_p^2 = .910$ . A main effect of proportion congruence was also observed,  $F(1, 19) = 4.51$ ,  $MSE = 1,525.59$ ,  $p = .047$ ,  $\eta_p^2 = .192$ . Most important, the main effects were qualified by a significant trial type by proportion congruence interaction,  $F(1, 19) = 12.73$ ,  $MSE = 550.29$ ,  $p = .002$ ,  $\eta_p^2 = .401$ , that revealed an ISPC effect. Stroop interference was reliably more pronounced for the mostly congruent ( $M = 111$  ms) as compared to the mostly incongruent ( $M = 73$  ms) items, an interaction that was driven by a significant 37 ms speeding of responses on mostly incongruent-incongruent relative to mostly congruent-incongruent trials,  $t(19) = 3.20$ ,  $SE_{diff} = 11.63$ ,  $p = .005$ .

For error rate, the main effect of trial type was significant,  $F(1, 19) = 14.14$ ,  $MSE = 0.001$ ,  $p = .001$ ,  $\eta_p^2 = .427$ , but the main effect of proportion congruence was not significant,  $F(1, 31) = 1.06$ ,  $MSE = 0.001$ ,  $p = .317$ ,  $\eta_p^2 = .053$ . The trial type by proportion congruence interaction was also not significant,  $F(1, 19) = 1.64$ ,  $MSE < 0.001$ ,  $p = .216$ ,  $\eta_p^2 = .079$ .

**Analysis of contingency: Training stimuli.** The obtainment of an ISPC effect could be driven by either modulation of word reading (i.e., control) or by associative learning mechanisms (i.e., contingencies), or by some combination of both. As suggested by Schmidt and Besner (2008), one approach to evaluating the contribution of contingency is to perform a  $2 \times 2$  repeated-measures ANOVA with trial type and contingency as factors. We conducted this contingency analysis on both the RT and error rate data. A main effect of contingency,  $F(1, 19) = 12.73$ ,  $MSE = 550.29$ ,  $p = .002$ ,  $\eta_p^2 = .401$ , and a main effect of trial type,  $F(1, 19) = 192.29$ ,  $MSE = 880.30$ ,  $p < .001$ ,  $\eta_p^2 = .910$ , were observed for RT, consistent with the contingency account. However, contrary to the predictions of the contingency account, the interaction between

contingency and trial type was also significant,  $F(1, 19) = 4.51$ ,  $MSE = 1,525.59$ ,  $p = .047$ ,  $\eta_p^2 = .192$ . This finding is consistent with the item-specific control account and the notion that the presently observed item-specific proportion congruence effect at least in part reflects the modulation of word reading and not simply stimulus-response learning.

As for error rate, the main effect of trial type was significant,  $F(1, 19) = 14.14$ ,  $MSE = 0.001$ ,  $p = .001$ ,  $\eta_p^2 = .427$ . Neither the main effect of contingency,  $F(1, 19) = 1.64$ ,  $MSE < 0.001$ ,  $p = .216$ ,  $\eta_p^2 = .079$ , or the Contingency  $\times$  Trial Type interaction,  $F(1, 19) = 1.06$ ,  $MSE = 0.001$ ,  $p = .317$ ,  $\eta_p^2 = .053$ , was significant.

**Analysis of transfer.** To determine whether differential modulation of word reading for mostly congruent and incongruent items was being signaled by the picture or the word, we next analyzed performance on the critical far transfer trials for which potential word and picture signals were in opposition. That is, the far transfer trials in which a mostly congruent word from training was paired with a picture from an animal category in the mostly incongruent training set were compared to the far transfer trials in which a mostly incongruent word from training was paired with a picture from an animal category in the mostly congruent training set (see Figure 1). Given the results of the contingency analysis and our a priori theoretical account, we predicted that the picture would be functioning as the ISPC signal and performance was therefore expected to be faster and more accurate for far transfer stimuli that included a mostly congruent word paired with a picture from the mostly incongruent training set. That is, because the picture signals a mostly incongruent control mode, and the trial itself is incongruent, the dampening of word reading that is presumably triggered by this mode should lead to faster and more accurate responding. Consistent with this prediction, dependent  $t$  tests revealed a 29-ms advantage in reaction time,  $t(19) = 1.54$ ,  $SE_{diff} = 19$ ,  $p = .140$  (two-tailed), and a 4.5% advantage in error rate,  $t(19) = 1.69$ ,  $SE_{diff} = 0.027$ ,  $p = .107$  (two-tailed). Performance was faster and more accurate on the far transfer incongruent trials that included a picture that was mostly incongruent and a word that was mostly congruent during training, RT:  $M = 721$  ( $SE = 29$ ); error rate:  $M = 0.050$  ( $SE = 0.017$ ), as compared to the

Table 3  
Mean Reaction Time in Milliseconds and Error Rates as a Function of Trial Type and Item-Specific Proportion Congruence in Experiments 1, 2, and 3

	Mostly congruent		Mostly incongruent	
	Congruent	Incongruent	Congruent	Incongruent
Reaction time				
Experiment 1: Training stimuli	601 (17)	711 (25)	601 (22)	674 (22)
Experiment 2: Training stimuli	617 (16)	728 (20)	620 (18)	693 (16)
Experiment 2: Transfer stimuli	624 (17)	718 (19)	631 (21)	693 (21)
Experiment 3: Training stimuli	608 (11)	712 (14)	636 (11)	712 (14)
Experiment 3: Transfer stimuli	628 (14)	728 (16)	652 (15)	725 (19)
Error rate				
Experiment 1: Training stimuli	.006 (.001)	.040 (.010)	.007 (.003)	.029 (.007)
Experiment 2: Training stimuli	.007 (.002)	.059 (.011)	.009 (.003)	.030 (.008)
Experiment 2: Transfer stimuli	.008 (.005)	.044 (.014)	.008 (.005)	.032 (.015)
Experiment 3: Training stimuli	.006 (.001)	.054 (.009)	.010 (.003)	.038 (.006)
Experiment 3: Transfer stimuli	.007 (.004)	.055 (.010)	.002 (.002)	.034 (.009)

Note. Standard errors are given in parentheses.

far transfer incongruent trials that included a picture that was mostly congruent and a word that was mostly incongruent during training, RT:  $M = 750$  ( $SE = 31$ ); error rate:  $M = 0.095$  ( $SE = 0.021$ ). Although these effects did not reach the threshold for statistical significance, the magnitude and direction of the advantage in RT and error rate is entirely consistent with the notion that the picture is functioning as the ISPC signal used to modulate word reading. Because these advantages were observed on opposition trials, it is plausible that the effects were somewhat contaminated by the presence of the word. That is, although there is no suggestion that the word was the primary signal (the direction of the advantages are completely opposite of the pattern one would obtain if the word was the signal) in the present paradigm, the word was nonetheless associated with a level of proportion congruence that was opposite that of the picture.

## Discussion

Experiment 1 provided an initial test of our broader theoretical analysis of ISPC effects. One novel finding is the observation of an ISPC effect in a picture-word Stroop task in which participants named the animal in the picture and ignored the animal word. Consistent with prior color-word Stroop studies (e.g., Bugg et al., 2008; Jacoby et al., 2003), interference was significantly attenuated for mostly incongruent as compared to mostly congruent items. Theoretically, an item-specific control mechanism or contingency learning could produce this ISPC effect. The results of the contingency analysis indicate that the current effect cannot be accounted for by a pure contingency account (i.e., S-R learning). The pattern of means, instead, indicates a disproportionate effect of the current ISPC manipulation on incongruent trials, which is consistent with the idea that the ISPC effect at least in part reflects control over word reading (cf. Schmidt & Besner, 2008). We posit that words are processed and relied on to a greater degree for mostly congruent as compared to mostly incongruent items. This second novel finding contrasts with Schmidt and Besner's (2008) reanalysis of data from Jacoby et al.'s (2003) color-word ISPC study. Their reanalysis indicated that contingency learning mechanisms provide a complete account of the ISPC pattern. The differential contributions of control versus contingency learning mechanisms in the current study and that of Jacoby et al. may be tied to differences in the experimental context (e.g., the degree of dimensional imbalance), and in particular the signals used to direct processing.

A third, theoretically important question addressed in Experiment 1 concerned such signals. The question turns on which dimension (i.e., word or picture) is relied on as the signal because the ISPC manipulation used here and in previous color-word studies (Bugg et al., 2008, Experiment 1; Jacoby et al., 2003, Experiments 2a, 2b, & 3) entailed sets that are composed of pictures (or colors) and words that are equally predictive of the proportion congruency level of that set, and therefore could be used as ISPC signals. Motivated by our theoretical analysis, we assume that the psychophysical and set size contexts in the present study shifted dimensional imbalance away from the word and increased the surprisingness of the relevant dimension such that participants' attention was biased toward the informational value (i.e., correlation with proportion congruency) of the picture. The analysis of performance on the incongruent far transfer trials

favored the conclusion that the picture was the signal participants were utilizing to differentially modulate control over reliance on the word.

In summary, the results of Experiment 1 provide preliminary support for two primary tenets of our theoretical account of ISPC effects. One is that not all ISPC effects reflect solely S-R (i.e., contingency) learning mechanisms. Control mechanisms such as the modulation of word reading also play a role in the differential interference observed for mostly congruent and mostly incongruent items. This finding challenges a pure contingency account of proportion congruency effects (e.g., Schmidt & Besner, 2008). The second is that the dimension that is used as the dominant ISPC signal need not be the irrelevant one (i.e., the word) as has been the case in previous color-word Stroop studies, but can also be the relevant dimension (here, the picture). Together, our findings are consistent with the idea that shifting the ISPC signal to the relevant dimension may open the door for item-specific control to influence performance.

In the experiments that follow, we further examine this claim and the relationship between particular signals (i.e., irrelevant vs. relevant dimension) and particular mechanisms (i.e., contingency vs. control). We do so by implementing a new approach to the ISPC manipulation. In all prior studies investigating ISPC effects, including the training phase of Experiment 1, the mostly congruent and incongruent sets were not allowed to overlap. For example, if the words *DOG* and *FISH* were in a mostly incongruent set, they never appeared with the pictures associated with the mostly congruent set (e.g., bird or cat). Allowing the sets to overlap, as we do in Experiments 2 and 3, produces an experimental context in which only one of the two dimensions is a potent signal of proportion congruency. Thus, unlike in Experiment 1, in which the conditional probabilities of the word given the picture and vice versa were equivalent, in Experiments 2 and 3 words and pictures are no longer on equal footing with regard to the utility of each dimension as a predictor of ISPC. When sets overlap and pictures are assigned to be mostly congruent or mostly incongruent, the pictures are the potent signal of proportion congruency while the signaling properties of the words are disrupted. The reverse occurs when words are assigned to be mostly congruent or mostly incongruent. The value of this approach is that it allows one to examine the relationship between particular signals (i.e., picture vs. word dimension) and particular mechanisms (i.e., control vs. contingency, respectively) used to direct processing.

If our theoretical analysis is correct, then the ISPC pattern should be characterized by use of control when the experimental context strongly biases participants toward reliance on the picture as the signal of proportion congruency (Experiment 2). Again, this is because proportion congruency is not confounded with contingency when the ISPC signal is the picture. In contrast, when the experimental context biases participants toward reliance on the word (Experiment 3), the ISPC pattern should be characterized by use of contingency learning mechanisms. This is because proportion congruency is confounded with contingency when the ISPC signal is the word.

It is important to note that in the following experiments, the use of contingency learning mechanisms is examined via alternative comparisons, not the contingency analysis conducted in Experiment 1. This is because the overlapping sets design (Experiments 2 and 3) and the placement of the ISPC signal in the relevant

dimension (Experiment 3) precludes use of the contingency analysis, as is explained in more detail in the introduction to each experiment.

## Experiment 2

In Experiment 2, pictures were assigned to mostly congruent and incongruent sets. The incongruent trials within each set included pairings of pictures with words from the opposite set (i.e., the sets overlapped). For example, if pictures of birds were mostly congruent, they occurred infrequently as incongruent trials but when they did these pictures were paired equally often with the words *CAT*, *DOG*, and *FISH*. By this assignment, pictures of animals in two of the categories (e.g., birds and cats) signaled a proportion congruency of 75% congruent and pictures of animals in the remaining two categories (e.g., dogs and fish) signaled a proportion congruency of 25% congruent. In contrast, by this assignment, the proportion congruency signaled by the words was 56% for *BIRD* and *CAT* and 38% for *DOG* and *FISH*.

We predicted that altering dimensional correlation such that only the pictures were a potent signal of proportion congruency, in combination with the changes to the psychophysical context and set size context that were implemented in Experiment 1, would bias participants toward use of control mechanisms such that interference would be attenuated for the mostly incongruent pictures as compared to the mostly congruent pictures (i.e., an ISPC effect would be obtained). Most critical, our theoretical account predicts that the pattern of means representing the ISPC effect should be characterized by a pronounced difference in performance on the incongruent trials because the proportion congruency of these items differs. That is, performance should be faster for the mostly incongruent—incongruent relative to the mostly congruent—incongruent items if word reading is modulated as a function of ISPC, similar to the pattern obtained in Experiment 1.

With regard to examining the use of contingency mechanisms, when pictures are assigned to be mostly congruent or incongruent, the relevant dimension both determines proportion congruency and is the to-be-named dimension. Thus, as noted earlier and explicated in Table 1, the pictures correlate perfectly with the correct response (i.e., a picture of a bird mandates the same, “bird” response regardless of whether it is paired with a congruent or incongruent word) and critically this means that regardless of whether a picture is assigned to the mostly congruent or incongruent set, the contingency level (degree to which the picture stimulus predicts the response) is always 100% on both congruent and incongruent trials. If participants are simply producing responses associated with particular pictures, then given the absence of differences in contingency level one should not observe an ISPC effect. Most critical then, the key trial type for contrasting the control and contingency account is the incongruent trial type; only the control account would predict differential performance on the incongruent trials from the mostly congruent and mostly incongruent conditions.

We also investigated performance on a set of transfer trials that were identical to those used in Experiment 1. Unlike Experiment 1, however, the distinction between near and far transfer trials is not relevant because the training stimuli were created by allowing the mostly congruent and mostly incongruent sets to overlap. Inclusion of transfer trials in the current experiment allows us to

address an intriguing question that was motivated by the transfer effect in Experiment 1. That is, the RT and error rate advantages we observed for transfer stimuli that included pictures from an animal category in the mostly incongruent relative to the mostly congruent training set hints at the possibility that participants were using a control mechanism that operated at the level of categories. Recall that the pictures used to create the transfer stimuli were completely novel and not encountered during the first two training blocks, and the transfer stimuli were 50% congruent and 50% incongruent. Yet, the control settings associated with particular categories of animals during training were transferred to these new pictures. Our manipulation of set size context for the relevant picture dimension may have inadvertently led participants to form a representation of the categories of items that were mostly congruent and incongruent, and use “category-specific control” settings to guide responding. If a similar mechanism were used in the current experiment, then we would expect an ISPC effect for transfer stimuli.

## Method

**Participants.** There were 16 undergraduates (six men, 10 women) aged 18 to 21 years at Washington University in St. Louis who participated for course credit or \$10. All participants provided informed consent, and were native English speakers with normal or corrected vision.

**Materials and design.** The materials and design were identical to Experiment 1, including the stimuli used to create the training and transfer items, with the following exceptions. Within the first two training blocks, pictures assigned to the mostly congruent set (e.g., four different birds and four different cats) were presented nine times each as a congruent item (i.e., the word *BIRD* or *CAT*, respectively, was superimposed on the pictures), and three times each as an incongruent item (e.g., each bird was paired once with *CAT*, once with *FISH*, and once with *DOG*). Pictures assigned to the mostly incongruent set (e.g., four different dogs and four different fish) were presented three times each as a congruent item, and nine times each as an incongruent item (e.g., each dog was paired three times with *BIRD*, three times with *CAT*, and three times with *FISH*; see Table 2 for the frequency of picture/word pairings). Assignment of pictures to the mostly congruent or mostly incongruent condition was counterbalanced across participants. As such the pictures in the mostly congruent set were 75% congruent and 25% incongruent whereas the pictures in the mostly incongruent set were 25% congruent and 75% incongruent. In contrast, following from the above example, the words *BIRD* and *CAT* were 56% congruent and 44% incongruent while the words *DOG* and *FISH* were 38% congruent and 62% incongruent.

**Procedure.** The procedure was identical to Experiment 1 except that there were four fewer trials in the third and final block.

## Results

As in Experiment 1, RTs less than 200 ms or greater than 3,000 ms were removed, which eliminated less than 1% of the trials.

**Analysis of proportion congruency: Training stimuli.** The mean RTs and error rate are presented in Table 3. The RTs and error rate for the training stimuli were submitted to  $2 \times 2$  repeated-

measures ANOVAs with trial type (congruent vs. incongruent) and proportion congruence (mostly congruent vs. mostly incongruent) as factors. For RT, significant Stroop interference ( $M = 92$  ms) was observed as indicated by the main effect of trial type,  $F(1, 15) = 154.04$ ,  $MSE = 876.33$ ,  $p < .001$ ,  $\eta_p^2 = .911$ . In addition, the ANOVA revealed a main effect of proportion congruence,  $F(1, 15) = 6.88$ ,  $MSE = 604.76$ ,  $p = .019$ ,  $\eta_p^2 = .314$ . As in Experiment 1, these effects were qualified by a Trial Type  $\times$  Proportion Congruence interaction,  $F(1, 15) = 14.97$ ,  $MSE = 407.85$ ,  $p = .002$ ,  $\eta_p^2 = .500$ , which indicated a significant ISPC effect. Interference was attenuated for pictures that were mostly incongruent (73 ms) as compared to pictures that were mostly congruent (111 ms). As can be seen in Figure 2, and consistent with the notion that a control mechanism is operative, this interaction is driven by a significant 36 ms speeding of responses on the mostly incongruent-incongruent as compared to mostly congruent-incongruent trials,  $t(15) = 3.76$ ,  $SE_{diff} = 15.43$ ,  $p = .002$ . RT on the congruent trials in the mostly congruent and mostly incongruent conditions did not differ,  $t(15) = -0.57$ ,  $p = .581$ .

For error rate, the main effect of trial type was significant,  $F(1, 15) = 26.82$ ,  $MSE = 0.001$ ,  $p < .001$ ,  $\eta_p^2 = .641$ , as was the main effect of proportion congruence,  $F(1, 15) = 7.58$ ,  $MSE < 0.001$ ,  $p = .015$ ,  $\eta_p^2 = .336$ . These effects were qualified by a significant Trial Type  $\times$  Proportion Congruence interaction indicative of an ISPC effect,  $F(1, 15) = 11.37$ ,  $MSE < 0.001$ ,  $p = .004$ ,  $\eta_p^2 = .431$ . Consistent with the RT pattern, the magnitude of interference in error rate was significantly smaller for mostly incongruent as compared to mostly congruent pictures.

**Analysis of proportion congruency: Transfer stimuli.** An identical set of analyses to those described above for the training stimuli was conducted for the transfer stimuli. For RT, a main effect of trial type was observed,  $F(1, 15) = 49.44$ ,  $MSE = 1,956.87$ ,  $p < .001$ ,  $\eta_p^2 = .767$ . The main effect of proportion congruence was not significant,  $F < 1$ . Most critical, the Trial Type  $\times$  Proportion Congruence interaction was significant,  $F(1, 15) = 10.24$ ,  $MSE = 408.23$ ,  $p = .006$ ,  $\eta_p^2 = .406$ , indicating that an ISPC effect was obtained for the transfer trials. Interference was less pronounced for new pictures from the animal categories in the

mostly incongruent training set ( $M = 62$  ms) as compared to new pictures from the categories in the mostly congruent training set ( $M = 94$  ms). As was found for the training trials, this interaction reflects the difference in RT on incongruent trials in the mostly congruent and incongruent conditions,  $t(15) = 2.35$ ,  $SE_{diff} = 10.66$ ,  $p = .033$  (see Figure 2). RT on congruent trials did not differ between these two conditions,  $t(15) = -0.63$ ,  $p = .540$ .

As for error rate, a main effect of trial type,  $F(1, 15) = 26.82$ ,  $MSE = .001$ ,  $p = .002$ ,  $\eta_p^2 = .477$  was observed. The main effect of proportion congruence,  $F < 1$ , and the Trial Type  $\times$  Proportion Congruence interaction,  $F < 1$ , were not significant.

## Discussion

Through use of a novel overlapping sets design, we altered dimensional correlation such that pictures were a potent signal of proportion congruency and words were not. An ISPC effect was observed with interference being reduced for the mostly incongruent as compared to mostly congruent pictures. Critically, the pattern of means reflecting the ISPC effect indicated a disproportionate effect of the ISPC manipulation on incongruent trials, with little to no effect on congruent trials. This pattern replicates that which was observed for Experiment 1, in which pictures and words were equally potent signals of ISPC but the psychophysical and set size context presumably biased reliance on the picture and use of control. Indeed, it is unclear how much the psychophysical and set size context as compared to the overlapping sets design and alteration of dimensional correlation influenced the emergence of control in the present experiment. The effect size for the ISPC effect was similar, albeit slightly larger in the present experiment (.50) than in Experiment 1 (.40). The most conservative conclusion is that biased use of the picture, through the combined set of context manipulations, produced the observed ISPC pattern.

The observed ISPC pattern is also consistent with our theoretical analysis, and in particular the idea that control is operative when the relevant dimension functions as the dominant signal of proportion congruence. We posit that participants differentially modulate the influence of word reading for incongruent pictures from

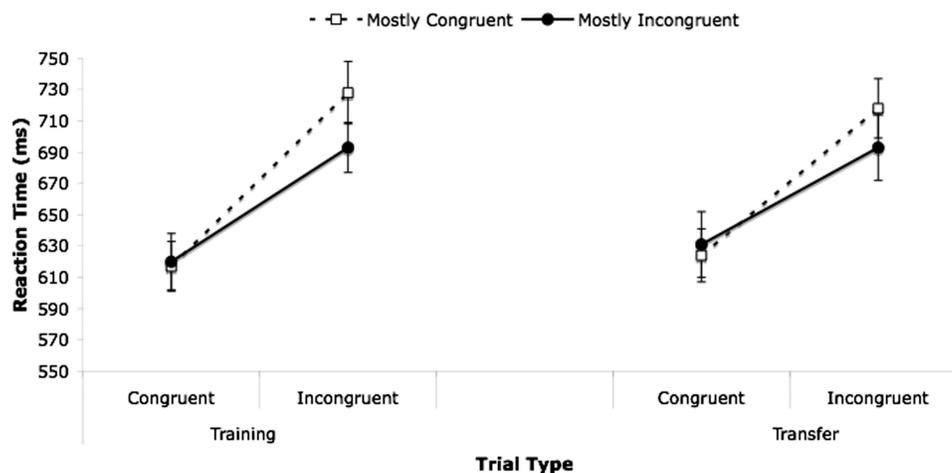


Figure 2. Magnitude of Stroop interference for training and transfer trials as a function of item-specific proportion congruence (mostly congruent vs. mostly incongruent) in Experiment 2.

the mostly incongruent and mostly congruent conditions, with processing of and reliance on the word being greater in the mostly congruent condition where processing of words often facilitates performance. As postulated by others (Schmidt & Besner, 2008), such a mechanism should indeed have a particularly pronounced effect on incongruent trials because the Stroop effect is predominantly driven by interference. The presence of the ISPC effect also argues against the idea that a contingency learning mechanism was operative whereby participants used the pictures to predict responses. Because pictures perfectly predict the correct response on all trial types (i.e., contingency is controlled), use of a contingency mechanism could not produce either the ISPC effect or the difference in performance on incongruent trials.

A second, theoretically important finding in the present experiment was the observation of an ISPC effect for the transfer trials. Like the training trials, this interaction again reflected the disproportionate influence of the ISPC manipulation on the incongruent trials. Therefore, it is reasonable to conclude that performance on the transfer trials also reflects the operation of a control mechanism. An interesting question concerns the level at which this control mechanism is operating. That is, because the transfer trials were composed of new pictures from each of the four animal categories it is possible that participants modulated word reading differentially for mostly congruent versus mostly incongruent categories of items not individual items per se. The fact that participants were exposed to four different exemplars of each category (due to the set size context manipulation) during training may have facilitated use of categorical rather than item level information. Of course it could also be the case that participants readily extract particular features associated with a given set of items (e.g., a beak for the bird category) and modulate control differentially for items that do or do not have this feature. Regardless, this issue merits further investigation as it suggests a potentially more efficient mode of organizing and implementing control.

### Experiment 3

In Experiment 3, we attempt to reverse the pattern that was observed in Experiments 1 and 2. In particular, we ask the question of whether altering dimensional correlation such that the words are the potent signal of proportion congruency is associated with use of contingency learning mechanisms. We address this question by assigning words, rather than pictures, to be mostly congruent or mostly incongruent. This is the single difference between the design of Experiments 2 and 3. In fact, we maintained the same psychophysical and set size contexts used in Experiment 2 so that any differences in the ISPC pattern (and the underlying mechanisms) are attributable to the enhanced utility of the word signal and disruption of the picture signal, not varying features of the experimental context.

We predicted that an ISPC effect would be observed, with interference being larger for the mostly congruent as compared to mostly incongruent words. In contrast to Experiment 2, however, we predicted that the ISPC pattern would be characterized by use of contingency learning mechanisms. Although Experiment 3 more closely resembles prior studies in which Schmidt and Besner's (2008) contingency analysis has been applied in that words are assigned to be mostly congruent or incongruent and therefore differentially predict particular responses, it was not

possible to test this prediction by conducting the contingency analysis. Unlike previous investigations involving two-item, non-overlapping sets (Bugg et al., 2008, Experiment 1; Jacoby et al., 2003, Experiments 2a, 2b, & 3) including the current Experiment 1, only a single cell (the mostly congruent-congruent trials) is of the high contingency type in the current overlapping sets design. There is no high contingency cell for incongruent trials for comparison. The mostly incongruent-incongruent trials, which were considered to be of the high contingency type in previous investigations, include pairings of each word with each of three categories of animal pictures (and thereby, three possible responses that are equally frequent) in the current design. As such, these trials are of the low contingency type. An alternative approach to investigating the role of contingencies is therefore needed.

We examine whether contingency learning accounts for the ISPC pattern in Experiment 3 by comparing performance on the high contingency-congruent trials (i.e., mostly congruent-congruent) to the low contingency-congruent trials (i.e., mostly incongruent-congruent). If contingency learning mechanisms are operative, an advantage in processing congruent items from the mostly congruent word set relative to congruent items from the mostly incongruent word set is expected. This is because the word correctly predicts the response on 75% of the trials for mostly congruent-congruent items (i.e., high contingency items), but the response to the mostly incongruent-congruent items is only weakly predicted by the word (i.e., low contingency items). Use of contingency learning mechanisms should not, however, lead to differential performance on the incongruent trials from each condition. This is because there are three possible responses on the incongruent trials in the mostly congruent and mostly incongruent condition. As such, there is an equally low likelihood (33%) that the correct response will be predicted for mostly congruent-incongruent and mostly incongruent-incongruent items. Use of a control mechanism, in contrast, would lead to a performance advantage for the mostly incongruent-incongruent items relative to the mostly congruent-incongruent items because these items do differ in proportion congruency (75% vs. 25%) and any modulation of word reading via control should have a particularly pronounced effect on incongruent trials.

As in the prior experiments, transfer trials were included. To the extent that contingency learning mechanisms are operative during the training trials, one would also expect such mechanisms to impact performance similarly on the transfer trials because the same words are superimposed on both types of trials.

### Method

**Participants.** There were 32 undergraduates (12 men, 20 women) aged 18 to 21 years at Washington University in St. Louis who participated for course credit or \$10. All participants provided informed consent, and were native English speakers with normal or corrected vision.

**Materials and design.** The materials and design were identical to Experiment 2 with the following exception. Within the first two training blocks, a word assigned to the mostly congruent set (e.g., *BIRD*) was presented nine times with each of the four congruent pictures (e.g., birds), and once with each of the 12 incongruent pictures from both sets (e.g., cats, dogs, fish). A word assigned to the mostly incongruent set (e.g., *DOG*) was presented

three times with each of the four congruent pictures, and three times with each of the 12 incongruent pictures from both sets (e.g., birds, cats, fish; see Table 2 for the frequency of picture/word pairings). As such the words in the mostly congruent set were 75% congruent and 25% incongruent whereas the words in the mostly incongruent set were 25% congruent and 75% incongruent. Following from the above example, in the current overlapping sets design, the bird and cat pictures were 56% congruent and 44% incongruent and the dog and fish pictures were 38% congruent and 62% incongruent.

**Procedure.** The procedure was identical to Experiment 2, including the inclusion of transfer trials.

## Results

As in the previous experiments, RTs less than 200 ms or greater than 3,000 ms were removed, which eliminated less than 1% of the trials.

**Analysis of proportion congruency: Training stimuli.** The mean RTs and error rate are presented in Table 3. First, we analyzed RT and error rate on the training stimuli using a  $2 \times 2$  repeated-measures ANOVA with trial type (congruent vs. incongruent) and proportion congruence (mostly congruent vs. mostly incongruent) as factors. A main effect of trial type,  $F(1, 31) = 227.95$ ,  $MSE = 1,133.05$ ,  $p < .001$ ,  $\eta_p^2 = .880$ , and a main effect of proportion congruence were observed,  $F(1, 31) = 25.08$ ,  $MSE = 252.08$ ,  $p < .001$ ,  $\eta_p^2 = .447$ . Most important, the main effects were qualified by a significant trial type by proportion congruence interaction,  $F(1, 31) = 11.63$ ,  $MSE = 479.99$ ,  $p = .002$ ,  $\eta_p^2 = .273$ , that revealed an ISPC effect. Stroop interference was reliably more pronounced for the mostly congruent ( $M = 103$  ms) as compared to the mostly incongruent ( $M = 77$  ms) items. As shown in Figure 3, and in contrast to the pattern from Experiment 2 (see Figure 2), the current interaction is driven entirely by differences in RT on the congruent trials from the mostly congruent and mostly incongruent conditions,  $t(31) = -4.93$ ,  $SE_{diff} = 5.53$ ,  $p < .001$ . This pattern is perfectly consistent with a contingency account because the response on mostly congruent-

congruent trials is strongly predicted by the word whereas the response on the mostly incongruent-congruent trials is weakly predicted by the word. RT did not differ on the incongruent trials from each condition,  $t(31) = -0.22$ ,  $p = .83$ . Again, this finding is consistent with a contingency account because prediction of the correct response on the incongruent trials from the mostly congruent and mostly incongruent conditions was equally unlikely (33% chance of predicting the correct of three possible responses).

The results for error rate were quite similar to the RT data. The main effect of trial type was significant,  $F(1, 31) = 28.25$ ,  $MSE = 0.002$ ,  $p < .001$ ,  $\eta_p^2 = .477$ , and the main effect of proportion congruence approached significance,  $F(1, 31) = 3.93$ ,  $MSE < 0.001$ ,  $p = .056$ ,  $\eta_p^2 = .113$ . Again, the ISPC effect was obtained as evidenced by a significant trial type by proportion congruence interaction,  $F(1, 31) = 11.68$ ,  $MSE < 0.001$ ,  $p = .002$ ,  $\eta_p^2 = .274$ . Stroop interference in error rate was larger for the mostly congruent ( $M = .05$ ) as compared to the mostly incongruent ( $M = .03$ ) items.

**Analysis of proportion congruency: Transfer stimuli.** Next, we analyzed RT and error rate for the transfer stimuli using the same  $2 \times 2$  repeated measures ANOVA. The main effect of trial type was significant,  $F(1, 31) = 84.32$ ,  $MSE = 2,846.89$ ,  $p < .001$ ,  $\eta_p^2 = .731$ , but the main effect of proportion congruence was not significant,  $F(1, 31) = 2.36$ ,  $MSE = 1,429.53$ ,  $p = .135$ ,  $\eta_p^2 = .071$ . The primary finding was an interaction between proportion congruence and trial type that strongly approached significance,  $F(1, 31) = 4.17$ ,  $MSE = 1,343.01$ ,  $p = .050$ ,  $\eta_p^2 = .119$ . As with the ISPC effect observed for the training stimuli, Stroop interference was more pronounced for transfer stimuli that were accompanied by words that were mostly congruent ( $M = 100$  ms) as compared to words that were mostly incongruent ( $M = 73$  ms). It is important to note that as shown in Figure 3, this interaction was driven by differences in RTs on the congruent trials from the mostly congruent and incongruent conditions,  $t(31) = -2.63$ ,  $SE_{diff} = 8.93$ ,  $p = .013$ , consistent with the training effect.

For error rate, a significant main effect of trial type was observed,  $F(1, 31) = 36.67$ ,  $MSE = 0.001$ ,  $p < .001$ ,  $\eta_p^2 = .542$ , and

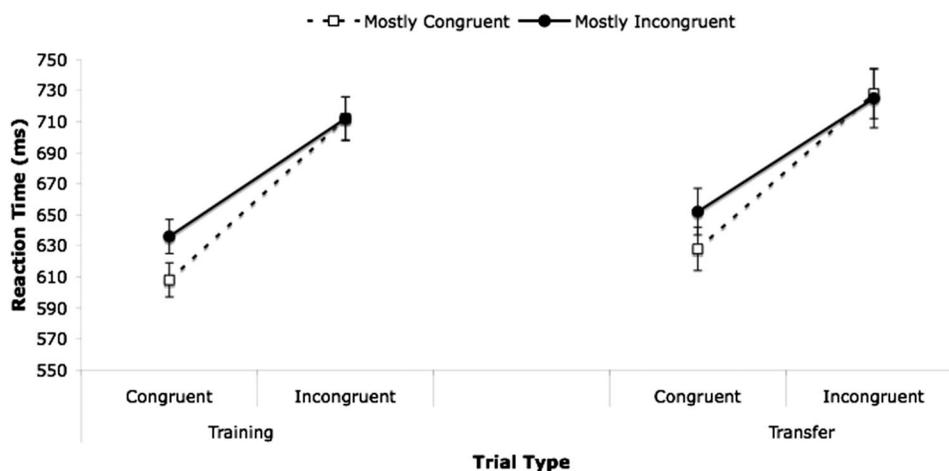


Figure 3. Magnitude of Stroop interference for training and transfer trials as a function of item-specific proportion congruence (mostly congruent vs. mostly incongruent) in Experiment 3.

the main effect of proportion congruence strongly approached significance,  $F(1, 31) = 4.02$ ,  $MSE = 0.001$ ,  $p = .054$ ,  $\eta_p^2 = .115$ . However, the proportion congruence by trial type interaction was not significant,  $F(1, 31) = 1.16$ ,  $MSE = 0.002$ ,  $p = .290$ ,  $\eta_p^2 = .036$ .

## Discussion

In the current experiment, an ISPC effect was observed with interference being larger for the mostly congruent relative to mostly incongruent words. The finding of an ISPC effect in the present picture-word paradigm, in which participants again named the animal in the picture and ignored the word, replicates Experiments 1 and 2. In striking contrast to Experiments 1 and 2, however, the ISPC effect in the present experiment was driven entirely by better performance on the congruent trial type from the mostly congruent as compared to the mostly incongruent condition. This is the pattern one would expect if contingency mechanisms were used to guide responding because the contingency level of the congruent trials in the mostly congruent condition was high whereas the contingency level of the congruent trials in the mostly incongruent condition was low. There was no difference in performance on the incongruent trials from each condition. This, too, is consistent with a contingency account because the contingency level for both the mostly congruent-incongruent and mostly incongruent-incongruent trials was low. The absence of an effect on incongruent trials is also consistent with the notion that control mechanisms were not operative in the present experiment. If they were operative, one would have expected performance to vary as a function of the proportion congruency level of the incongruent trials (i.e., greater dampening of the word reading process and, hence, faster RTs for the mostly incongruent-incongruent trials), as was found in Experiments 1 and 2. The findings, therefore, support the notion that the ISPC effect in the present picture-word Stroop paradigm was driven by reliance on contingency learning mechanisms.

We can be reasonably confident that the locus of the shift in use of control versus contingency learning mechanisms from Experiment 2 to Experiment 3 relates to differential reliance on the picture versus word signals, respectively. This is because the single difference between these experiments was which of the two dimensions was designated, via the overlapping sets design, as the potent signal of proportion congruency. Both the psychophysical and set size contexts were identical across the experiments. In other words, even though the psychophysical and set size contexts presumably biased participants toward evaluating the informational value of the relevant picture dimension in the current experiment (as in previous experiments), the fact that the word strongly signaled proportion congruency (and contingency) biased participants toward reliance on it and use of contingency learning mechanisms. This raises the possibility of a potential hierarchy of tectonic structures (cf. Crump, Vaquero, & Milliken, 2008; Dishon-Berkovits & Algom, 2000). For example, the covariate context (i.e., dimensional correlation), through its ability to dictate both contingencies and proportion congruency, may be the primary determinant of which of the two dimensions is relied on as the signal and the resultant mechanisms. When one dimension is a particularly potent signal of proportion congruency, it may undermine the potency of other structures such as dimensional imbalance to influence these outcomes, as appears to be the case in the present experiment. When the degree to which each dimension

signals proportion congruency is equated, as in Experiment 1, then other structures such as dimensional imbalance may be more potent determinants of signals and use of particular mechanisms.

A second important finding in the current experiment was the generalization of the ISPC effect to a set of transfer stimuli that were 50% congruent and 50% incongruent. The pattern of means replicated those that were observed for the training stimuli, with interference being attenuated for transfer stimuli that included a mostly incongruent word relative to a mostly congruent word from training. It is important to note that as was the case for the training stimuli, the difference in performance between high-contingency congruent and low-contingency congruent trials drove the interaction. In the current context, this finding suggests that contingency learning mechanisms (i.e., production of responses associated with particular words) can be applied to new picture/word pairings so long as the word signal to which these mechanisms are tied is intact for such stimuli and the correct response matches the response that is predicted via experience with the training stimuli.

## General Discussion

A major finding in this study is the obtainment of an ISPC effect that cannot be accounted for by contingency learning mechanisms. This finding was first demonstrated in Experiment 1 in which the typical ISPC design involving two-item, nonoverlapping sets was implemented. In Experiment 1, the results of the contingency analysis (Schmidt & Besner, 2008) for reaction time ran counter to the predictions of the contingency account. The pattern of means, instead, was consistent with an item-specific control mechanism, such as differential modulation of word reading for mostly congruent and mostly incongruent items, which disproportionately influenced performance on incongruent trials (cf. Schmidt & Besner, 2008). A conceptual replication of this ISPC effect was obtained in Experiment 2 in which we implemented a novel, overlapping sets design and the picture was designated as the potent proportion congruency signal. Consistent with the control account, there was a disproportionate influence of the ISPC manipulation on incongruent trials. As in Experiment 1, performance was faster on mostly incongruent-incongruent relative to mostly congruent-incongruent trials, trials that quite obviously differed with regard to proportion congruency. According to a contingency account, such a difference would not be expected because contingencies were equated for these trial types (i.e., the picture perfectly predicts the correct response for incongruent trials in both conditions), and the use of contingency mechanisms would therefore produce equivalent performance.

The findings of Experiment 1 and 2 support our broader theoretical account of ISPC effects and challenge the notion that item-specific proportion congruence effects can be accounted for entirely by contingency learning mechanisms, as the contingency account of proportion congruency effects suggests (Schmidt & Besner, 2008). This is not to say that we dispute the idea that contingency plays a role in ISPC effects, rather, the current data suggest that contingency is not the entire story. Indeed, a primary contribution of the present study is the elucidation of task parameters that govern reliance on control versus contingency mechanisms in producing the ISPC pattern. The key parameter uncovered here pertains to the dimension that functions as the dominant signal of proportion congruency. As just reviewed, in the experi-

ments in which the dominant signal was the relevant dimension (Experiments 1 and 2), the ISPC pattern was consistent with use of a control mechanism. In contrast, when the irrelevant word was the dominant signal of proportion congruency in an overlapping sets design in Experiment 3, the ISPC pattern was as one would expect if participants were using a contingency learning mechanism. Specifically, there was no difference in performance on the incongruent trials from the mostly congruent and mostly incongruent conditions, trials for which there was a low likelihood of predicting the correct response. Performance was, however, better on the high contingency, mostly congruent-congruent relative to the low contingency, mostly incongruent-congruent trials. This finding supports the contingency account (Schmidt & Besner, 2008).

### Alternative Accounts

One of the key findings in support of a control account in Experiments 1 and 2 is the ISPC pattern itself, and in particular the speeded responding observed on mostly incongruent-incongruent as compared to mostly congruent-incongruent trials. Although we have effectively ruled out differential contingencies as an explanation for this speeded responding, some might point out that we did not control for the frequency with which mostly incongruent-incongruent and mostly congruent-incongruent trials were presented. One could argue, for example, that the RT advantage for mostly incongruent-incongruent trials relative to mostly congruent-incongruent trials may simply reflect the differential frequencies with which participants viewed instances of the incongruent trials across the two conditions (cf. Logan, 1988). A frequency account, however, has difficulty explaining the entire pattern of results across experiments. For instance, if the ISPC pattern, and in particular the difference in performance between the incongruent trials in Experiment 2 is dependent on the frequency of stimulus presentation, it is unclear why we obtained an ISPC transfer effect that was of a similar magnitude to that observed during training (training effect size = .500, transfer effect size = .406) for frequency unbiased items. Moreover, and perhaps most critical, a frequency account cannot explain the ISPC pattern obtained in Experiment 3. In Experiment 3, it is still the case that mostly incongruent-incongruent trials are presented disproportionately more often than mostly congruent-incongruent trials, yet contrary to a frequency account there is no difference in performance for these trial types. Only the current theoretical account anticipated this finding on the basis that reliance on the word to produce responses would lead to equivalent performance on the low contingency incongruent trials from each condition.

One might also challenge our theoretical notion that it is the dominance of the relevant as compared to the irrelevant dimension as the signal of proportion congruency that is the key factor leading to use of item-specific control. An alternative explanation is that control may arise when contingency mechanisms are an ineffective means by which interference can be attenuated. Such an account accommodates the contrasting pattern of results in Experiments 2 and 3. However, it cannot account for the results of Experiment 1. Recall that in Experiment 1 both the irrelevant word and relevant picture dimension were equally predictive of proportion congruency, yet the response patterns suggested use of a mechanism other than contingencies underlying the ISPC effect. In other words, contingency mechanisms would have been a perfectly

effective approach to minimizing interference in Experiment 1 and still, evidence of control was observed. Moreover, in line with our theoretical account, the direction of the reaction time and error rate advantages on the far transfer (i.e., opposition) trials was consistent with the notion that participants were relying on the relevant picture dimension to govern the control mechanism.

### The Generality of Control in Proportion Congruency Effects

The current set of data demonstrates that it is premature to dismiss the contribution of control in ISPC effects. An important question, however, concerns the generality of control mechanisms relative to contingency mechanisms in ISPC effects, as well as in proportion congruency effects more generally. Whereas the findings of Experiment 3 support the generality of contingency mechanisms in ISPC effects, the question remains as to whether the use of control in proportion congruency effects such as the ISPC is specific to the current picture-word Stroop paradigm. We believe the answer is no. One reason is that our theoretical analysis is not limited to picture-word Stroop. Indeed, the notion that one can shift attention toward evaluating the informational value of the relevant dimension (e.g., by altering dimensional imbalance and surprisingness) is borne out of Melara and Algom's (2003) tectonic theory of color-word Stroop. Thus, it should be possible to further promote use of a control mechanism in color-word Stroop by altering dimensional imbalance and surprisingness, as our theory would suggest. Admittedly, this may be more challenging with color-word Stroop than in the picture-word Stroop task used here, which offered flexibility in manipulating the psychophysical and set size contexts.

A second reason we believe that control plays a role more generally in ISPC effects and is not limited to the present paradigm is that a control account of proportion congruency effects but not a contingency account has been shown to explain a range of proportion congruency effects in Stroop paradigms. For instance, neither the context-specific proportion congruence effect (the finding of attenuated Stroop interference for stimuli that appear in a mostly incongruent relative to a mostly congruent location, Crump, Gong, & Milliken, 2006; Crump et al., 2008) nor the font-specific proportion congruence effect (the finding of attenuated Stroop interference for stimuli that appear in a mostly incongruent as compared to mostly congruent font type, Bugg et al., 2008) can be explained by a simple contingency mechanism. In these paradigms, the signal of proportion congruency (e.g., location, font type) is associated equally often with all possible responses, and it is therefore not possible to predict the correct response on the basis of this signal. The context-specific and font-specific proportion congruence effects are, however, accounted for by a control mechanism. The presence of these effects, thus, lends credence to the generality of control mechanisms that involve rapid modulation of word reading (based on signals that are correlated with proportion congruency and present in a target display).

### The Nature of Control Mechanisms Underlying Proportion Congruency Effects

As proposed by Jacoby et al. (2003) in the context of color-word Stroop, item-specific control may be accomplished via the actions of a word-reading filter (see also Jacoby, McElree, & Trainham, 1999).

Such a control mechanism may be at play in the present picture-word Stroop paradigm. Indeed, a word-reading filter can account for the pattern observed on the incongruent trials in Experiments 1 and 2 where performance was faster for the mostly incongruent-incongruent trials relative to the mostly congruent-incongruent trials. This is the pattern one would expect if the irrelevant word is filtered more quickly when the picture signals that the current item is mostly incongruent as opposed to mostly congruent. Yet, the notion of a word-reading filter may seem counterintuitive. One might wonder why participants would not simply use the picture to respond (i.e., name the animal). This may relate to the speed with which each dimension is accessed. The word is presumably activated and “hanging around” when the picture is processed, and on half of the trials (i.e., those that are congruent) responding on the basis of the word is not costly. Processing of the picture may provide information regarding the likelihood of conflict or an error if one were to rely on the already processed word information. For instance, a mostly incongruent picture may signal that the likelihood of conflict or an error is high if the word is used to respond, thereby directing dampening of the word’s activation. It is plausible that participants have access to this information (i.e., the likelihood of conflict or an error) prior to the stage at which the picture can be named. That is, features that define particular animal categories or more general categorical information might be extracted relatively quickly (thus allowing participants to identify an item as mostly congruent or mostly incongruent), prior to complete processing of the picture (for a similar explanation of the font-specific proportion congruence effect, see Bugg et al., 2008).

It is not immediately clear, however, why such a filter did not produce slowing on the mostly incongruent-congruent trials relative to the mostly congruent-congruent trials in Experiments 1 and 2. If the word is filtered more quickly when the picture is mostly incongruent, then one might have expected reduced facilitation on the congruent trials in this condition. Indeed, this pattern has been observed for ISPC effects in color-word Stroop. One possibility for this discrepancy is that there may be an important difference between the target of control mechanisms in color-word and picture-word ISPC studies. For picture-word Stroop, a distinction between the identification and naming of pictures may be necessary. That is, participants may rather quickly identify a picture as a particular animal, and it is this identification that determines whether the current trial is a mostly congruent or mostly incongruent picture. Because naming may not be concurrent with identification and the correct name is primed by the irrelevant word on congruent trials, the name may be retrieved, evaluated, and a response decision made before control dampens activation of the word. In contrast, this delay between naming and identification may provide a window of opportunity for control to filter word reading on incongruent trials, thereby dampening activation of the irrelevant and incorrect response that is primed by the word.

Another possibility is that the slowing on mostly incongruent-congruent relative to mostly congruent-congruent trials in past color-word ISPC studies may reflect the contribution of contingency learning and not the contributions of control. As shown by Schmidt and Besner (2008), reliance on a contingency mechanism can produce the difference in performance on both incongruent and congruent trials as a function of ISPC for the nonoverlapping color-word Stroop design used previously. It is therefore possible that the dominance of contingency mechanisms in these prior studies produced the performance difference on the congruent

trials. By this view, the selective influence of the ISPC manipulation on the incongruent trials in the picture-word paradigms of Experiment 1 and Experiment 2 may be the pattern that one would expect if a word-reading filter were dominant. As Schmidt and Besner noted, any modulation of word reading should disproportionately influence incongruent trials.

Other models, too, anticipate that control might selectively influence performance on the incongruent trials. For instance, the item-specific conflict monitoring models of Blais, Robidoux, Risko, and Besner (2007) and Verguts and Notebaert (2008) posit that item-specific control is implemented when triggered by the presence of conflict. Conflict is apparent on incongruent but not congruent trials. Further, these models suggest that a higher degree of conflict should be associated with a stronger control signal, and this prediction finds support in Experiments 1 and 2 where performance is better for incongruent items from the mostly incongruent set (for which conflict is high) relative to incongruent items from the mostly congruent set (for which conflict is lower). One idea is that a conflict-monitoring module may signal when the word-reading filter is (on an incongruent trial) or is not needed (on a congruent trial), with the strength of the signal modulating the speed with which the irrelevant dimension is filtered. Another idea is that conflict may boost attention to the value of the relevant dimension (e.g., picture) that is associated with a particular item, either independent of (cf. Blais et al., 2007) or in addition to (cf. Verguts & Notebaert, 2008) dampening attention to the irrelevant word.

More broadly speaking, whether the same control mechanism underlies item-specific (Experiments 1 and 2) and other proportion congruency effects such as the context-specific (e.g., Crump et al., 2006) and font-specific (Bugg et al., 2008) effect is of theoretical interest. One apparent similarity is that control is triggered by a signal that provides information regarding proportion congruency (i.e., likelihood of conflict or error). A clear difference between the context- and font-specific paradigms and the picture-word paradigms that revealed item-specific control in Experiments 1 and 2, however, is the nature of the signal. Whereas the context-specific and font-specific effects entail a signal (i.e., location or font type) that need not be attended for participants to produce the correct response (i.e., the signal is not part of the response set), the signal of ISPC in the picture-word Stroop task lies in the relevant to-be-named dimension, which must be attended to produce the correct response (i.e., to the extent that the signal is the animal and not a feature, this signal is part of the response set). Thus, models of control for the context- and font-specific effects may need to include an additional step that describes the biasing of attention toward signals (e.g., particular locations, font types) that are technically irrelevant to task performance.

### The Flexibility of Item-Specific Mechanisms

A final issue that was addressed in the present study was transfer of control and contingency learning processes. We found that the ISPC effect generalized to frequency unbiased stimuli (presented equally often as congruent and incongruent) that were composed of one of the four animal words superimposed on a novel picture from one of the animal categories encountered during training. The obtainment of transfer suggests that differential processing of mostly congruent and mostly incongruent items is driven by the value of the dimension that is functioning as the ISPC signal (in Experiment 2, the picture; in

Experiment 3, the word) not by particular combinations of pictures and words. So long as the value encountered on the transfer trials is one of the training values, it appears that participants flexibly utilize the signal to either control word reading (Experiment 2) or predict particular responses (Experiment 3), just as they did on the training trials. The observation of the ISPC effect on the transfer trials in Experiment 2 is particularly intriguing. It suggests that the value of the signaling dimension (e.g., bird 5) on transfer trials need not perfectly match a value that was encountered during training (e.g., bird 1, 2, 3, or 4). Instead, a match at the category or feature level (e.g., bird or beak) seems sufficient to trigger control settings. This finding accords well with the recent observation that context-specific control settings generalize to novel, frequency unbiased items that appear in locations that signal either a mostly congruent or incongruent context (Crump & Milliken, 2009).

### Conclusions

In this paper, we have introduced and tested a broader theoretical account of ISPC effects. Our novel account (1) explains the seemingly obligatory use of contingency learning mechanisms in prior color-word Stroop ISPC studies (e.g., Schmidt & Besner, 2008, Re-analyses 1 & 2) as a function of reliance on the word dimension (due to dimensional imbalance) as the signal of proportion congruency, (2) highlights the absence of a confound between contingency and proportion congruency when it is the relevant dimension that is the signal of proportion congruency, and (3) predicts both an ISPC pattern not previously obtained that reflects dominance of control when the relevant dimension signals proportion congruency and the reversal of this pattern, implicating dominance of contingency mechanisms, when the irrelevant dimension signals proportion congruency. These predictions were supported by the current data and are therefore compatible with the Jacoby et al. (2003) view that both item-specific control and contingency learning mechanisms play a role in ISPC effects, and are incompatible with a pure contingency account (Schmidt & Besner, 2008).

### References

- 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.
- 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.
- Bugg, J. M., Jacoby, L. L., & Toth, J. P. (2008). Multiple levels of control in the Stroop task. *Memory & Cognition*, *36*, 1484–1494.
- Costa, A., Alario, F., & Caramazza, A. (2005). On the categorical nature of the semantic interference effect in the picture-word interference paradigm. *Psychonomic Bulletin & Review*, *12*, 125–131.
- Crump, M. J., Gong, Z., & Milliken, B. (2006). The context-specific proportion congruency effect: Location as a contextual cue. *Psychonomic Bulletin & Review*, *13*, 316–321.
- Crump, M. J., Vaquero, J. M. M., & Milliken, B. (2008). Context-specific learning and control: The roles of awareness, task relevance, and relative salience. *Consciousness & Cognition*, *17*, 22–36.
- Crump, M. J. C., & Milliken, B. (2009). The flexibility of context-specific control: Evidence for context-driven generalization of item-specific control settings. *Quarterly Journal of Experimental Psychology*, *62*, 1523–1532.
- 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.
- Fraisse, P. (1969). Why is naming longer than reading? *Acta Psychologica*, *30*, 96–103.
- Glaser, W. R., & Dungenhoff, F. J. (1984). The time-course of picture-word interference. *Journal of Experimental Psychology: Human Perception & Performance*, *10*, 640–654.
- Glaser, W. R., & Glaser, M. O. (1989). Context effect in Stroop-like word and picture processing. *Journal of Experimental Psychology: General*, *118*, 13–42.
- Jacoby, L. L., Lindsay, D. S., & Hessels, S. (2003). Item-specific control of automatic processes: Stroop process dissociations. *Psychonomic Bulletin & Review*, *10*, 638–644.
- 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. Koriati (Eds.), *Attention and performance XVII* (pp. 461–486). Cambridge, MA: Bradford, MIT Press.
- La Heij, W. (1988). Components of Stroop-like interference in picture naming. *Memory & Cognition*, *16*, 400–410.
- Leboe, L. C., & Mondor, T. A. (2007). Item-specific congruency effects in nonverbal auditory/Stroop. *Psychological Research*, *71*, 568–575.
- 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.
- Logan, G. D. (1988). Toward an instance theory of automatization. *Psychological Review*, *95*, 492–527.
- Logan, G. D., & Zbrodoff, N. J. (1979). When it helps to be misled: Facilitative effects of increasing the frequency of conflicting stimuli in a Stroop-like task. *Memory & Cognition*, *7*, 166–174.
- Lupker, S. J. (1979). The semantic nature of response competition in the picture-word interference task. *Memory & Cognition*, *7*, 485–495.
- MacLeod, C. M. (1991). Half a century of research on the Stroop effect: An integrative review. *Psychological Bulletin*, *109*, 163–203.
- Melara, R. D., & Algom, D. (2003). Driven by information: A tectonic theory of Stroop effects. *Psychological Review*, *110*, 422–471.
- 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.
- Musen, G., & Squire, L. R. (1993). Implicit learning of color-word associations using a Stroop paradigm. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, *19*, 789–798.
- Schmidt, J. R., & Besner, D. (2008). The Stroop effect: Why proportion congruency has nothing to do with congruency and everything to do with contingency. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, *34*, 514–523.
- Schmidt, J. R., Crump, M. J. C., Cheesman, J., & Besner, D. (2007). Contingency learning without awareness: Evidence for implicit control. *Consciousness and Cognition*, *16*, 421–435.
- Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology*, *18*, 643–661.
- Theios, J., & Amrhein, P. C. (1989). Theoretical analysis of the cognitive processing of lexical and pictorial stimuli: Reading, naming, and visual and conceptual comparisons. *Psychological Review*, *96*, 5–24.
- Verguts, T., & Notebaert, W. (2008). Hebbian learning of cognitive control: Dealing with specific and nonspecific adaptation. *Psychological Review*, *115*, 518–525.
- Virzi, R. A., & Egeth, H. E. (1985). Toward a translational model of Stroop interference. *Memory & Cognition*, *13*, 304–319.
- West, R., & Baylis, G. C. (1998). Effect of increased response dominance and contextual disintegration on the Stroop interference effect in older adults. *Psychology and Aging*, *13*, 206–217.

Received September 21, 2009

Revision received January 31, 2010

Accepted February 15, 2010 ■