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Congruency precues moderate item-specific proportion congruency effects

Keith A. Hutchison[1] **· Julie M. Bugg**[2] **· You Bin Lim**[2] **· Mariana R. Olsen**[1]

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Abstract The item-specific proportion congruency (ISPC) effect refers to the reduction in the Stroop effect for items (e.g., words) that mostly appear in an incongruent format, as compared to items that mostly appear in a congruent format. It is thought to demonstrate reactive control of word-reading processes. In the present study, we tested the hypothesis that using explicit, trial-by-trial congruency precues to proactively guide attention during a color-word Stroop task could reduce the otherwise robust ISPC effect. In Experiment 1, the precueing manipulation was employed alongside a manipulation traditionally thought to influence proactive control of word-reading processes (i.e., list proportion congruence [list PC]). Precueing participants with 100 %-valid precues eliminated both the ISPC effect and the list PC effect. In Experiment 2, we used 70 %-valid congruency precues to direct participants to generally expect conflict or congruence on a given trial. ISPC effects were selectively reduced when the participants expected conflict. These results suggest that precueing influences engagement in proactive control and, as a result, reduces the impact of item-specific and list-based tendencies to direct attention toward or away from word reading.

Keywords Stroop · Item-specific proportion congruency · Preparatory cues

✉ Keith A. Hutchison
khutch@montana.edu

[1] Department of Psychology, Montana State University, Bozeman, MT 59717, USA

[2] Department of Psychological and Brain Sciences, Washington University, St. Louis 63130, MO, USA

In the Stroop task, participants respond to the font color of a color word while ignoring the more dominant dimension of the stimulus, the color word itself. In spite of their intentions to ignore the irrelevant word, a large Stroop effect is routinely observed, reflecting slower and/or more errant responding on incongruent (e.g., RED displayed in blue) than on congruent (e.g., BLUE displayed in blue) trials (for a review, see MacLeod, 1991). An elegant account of the Stroop effect, referred to hereafter as the *correlation account* (see Melara & Algom, 2003), attributes failures of selective attention in the Stroop task to the powerful influence of the irrelevant yet predictive (i.e., attractive) word dimension. The primary tenets of this account are that irrelevant words become relevant through learned correlations with correct color responses, and that the information conveyed by such correlations is used to optimize performance (Algom, Dekel, & Pansky, 1996; Dishon-Berkovits & Algom, 2000; Sabri, Melara, & Algom, 2001; see also Melara & Mounts, 1993; Virzi & Egeth, 1985). According to the correlation account, the Stroop effect reflects that the irrelevant words are commonly correlated with the correct response—accordingly, attention is attracted to the predictive words, thereby undermining efforts to selectively attend to the color. The flipside is also true: When the irrelevant words are not correlated with the correct response, attention is repelled from them, and selective attention is more successful (e.g., the Stroop effect is reduced or eliminated; Dishon-Berkovits & Algom, 2000).

A relatively recent and exciting finding that resonates with the correlation account in demonstrating the powerful influence of information that is conveyed by nominally irrelevant words in the Stroop task is the *item-specific proportion congruency* (ISPC) effect. It refers to the pattern whereby the Stroop effect is attenuated for particular items (e.g., words) that mostly appear in an incongruent format (i.e., MI items), relative to items that are mostly congruent (e.g., MC items;

Jacoby, Lindsay, & Hessels, 2003; for evidence of ISPC effects in other conflict paradigms, see Bugg, 2015; Wendt & Luna-Rodriguez, 2009). Said differently, words that have routinely been paired with a congruent color, and are thereby predictive of the correct response, tend to attract attention, resulting in larger Stroop effects than do words that have routinely been paired with an incongruent color, and thereby divert attention away from word reading. Indeed, Jacoby et al. (2003) attributed the ISPC effect to the operation of mechanisms that automatically draw attention toward or away from specific distractor words on the basis of the likelihood that the words will interfere with responding.

The ISPC effect appears to be an extremely robust phenomenon (see Bugg & Crump, 2012), which is perhaps unsurprising, given that it appears to be caused by correlated information that is readily learned and is used seemingly automatically to bias attentional processes (Jacoby et al., 2003). However, the question we addressed in the present study is whether ISPC effects are at all mutable, and in particular whether they can be reduced or eliminated. Motivated by the dual-mechanisms-of-control account (Braver, Gray, & Burgess, 2007), which posits the existence of two distinct modes of control—proactive and reactive—we tested the hypothesis that encouraging participants to prepare proactively will attenuate the typically robust ISPC effect. The hypothesis hinges on two theoretical assumptions: (1) ISPC effects are caused by *reactive* modulations of attention that reflect learning processes (e.g., learning of stimulus–attention associations; Bugg & Crump, 2012; Crump & Milliken, 2009), and (2) the engagement of *proactive* control should interfere with the typical learning of information correlated with irrelevant words and/or with the deployment of reactive control (i.e., proactive and reactive control will interact). Below we detail the relevant assumptions of the dual-mechanisms-of-control account, and then survey the evidence supporting each of the assumptions above.

Dual mechanisms of control

According to the dual-mechanisms-of-control account (Braver et al., 2007; Braver, 2012), *proactive* control refers to a resource-demanding preparatory strategy aimed at minimizing interference before it arises. This form of control, which is similar to more classic conceptions of top-down control (Miller & Cohen, 2001; Posner & Snyder, 1975), relies on lateral prefrontal cortex (PFC) to maintain task goals in preparation for future events and allows early selection of task-appropriate information over distracting information. Whereas proactive control is dependent on reliable cues that predict the need for control (e.g., that predict frequent or high levels of conflict), *reactive* control, in contrast, is thought to be a late-selection mechanism that is triggered post-stimulus-onset. Reactive control may be elicited either through conflict between competing responses detected by the anterior cingulate cortex (ACC) or via episodic associations linked to a target stimulus (i.e., learned associations between a word and the likelihood that the word will interfere with one's goal, as in the ISPC effect).

The role of reactive control in the ISPC effect

The ISPC effect has been described as reactive because the effect emerges in 50 %-congruent blocks (i.e., lists) of a Stroop task in which MC and MI items are randomly intermixed. Critically, this means that one cannot predict whether the next item will be a word that is MC or a word that is MI. The attentional adjustments that lead to smaller Stroop effects for MI than for MC items must therefore occur reactively, post-stimulus-onset (i.e., are not caused by a preparatory mechanism such as proactive control).

A key point is that in an ISPC paradigm, consistent with the correlation account (Melara & Algom, 2003), it is assumed that participants accumulate experience with MC and MI words, and this experience supports the learning of information that is correlated with these words. When stimuli are subsequently presented, learned information is retrieved and applied reactively, resulting in smaller (i.e., MI word presented) or larger (i.e., MC word presented) Stroop effects. Importantly, there is evidence that such information is not merely stimulus–response associations; rather, participants appear to learn more abstract stimulus–attention associations (e.g., MI word—minimize attention to the word). For instance, Bugg and Hutchison (2013) demonstrated that ISPC effects for MI words could occur even when these words were (later) presented in new colors, showing that these words bias attention away from word reading in general, rather than simply triggering a learned associative response.

Interactivity of proactive and reactive control

Although Braver et al. (2007) have posited that reactive and proactive control are dissociable, often the two forms of control may interact, such that greater use of proactive control in the Stroop task should lead to less interference from the irrelevant word, and thus a reduced need for reactive control. Indeed, as Braver et al. stated, proactive control "leads to a reduction in incidental encoding of goal-irrelevant or goal-incongruent features" (p. 84). Thus, it is reasonable to expect that situations in which proactive control is enhanced should lead to reductions in reactive control, as evidenced by the magnitude of the ISPC effect. As we described above, such control depends on learning the relationship between irrelevant words and their likelihood of interfering with the goal of color naming. Some evidence for such interactivity between proactive and reactive control exists within the neuroimaging literature. For example, De Pisapia and Braver (2006) found neuroimaging evidence that transient and target-cued ACC activation, typically argued to be indicative of reactive control, was attenuated in *lists* of trials that were MI (as compared to MC). Critically, in these lists there was evidence for sustained activation of lateral PFC, suggestive of heightened proactive control (cf. MacDonald et al., 2000).

In addition to this neuroimaging evidence, some behavioral evidence also supports the interactivity of proactive and reactive control in studies employing list-based PC manipulations (i.e., contrasting Stroop effects in MC and MI lists; e.g., Gratton, Coles, & Donchin, 1992; Hommel, 1994; Kane & Engle, 2003; Logan & Zbrodoff, 1979, 1982; Long & Prat, 2002). Specifically, Hutchison (2011) found that ISPC effects were larger in MC than in MI lists. Because proactive control has traditionally been assumed to be greater for MI lists (Cohen, Dunbar, & McClelland, 1990; Kane & Engle, 2003), this was taken as evidence for interactivity, such that the tendency for MC words to draw attention toward word reading was greater when top-down control was relaxed (cf. Abrahamse, Duthoo, Notebaert, & Risko, 2013). Second, and also consistent with this interactivity account, there was a significant negative correlation between working memory capacity (WMC; i.e., operation span [OSPAN] scores) and ISPC effects in Hutchison's study. ISPC effects decreased with increasing WMC. This difference in ISPC effects was due to low-WMC individuals being particularly impaired on MC items, which attract attention toward word reading, perhaps because top-down proactive control was deficient in these individuals. However, this effect was observed only for error rates.

Although these patterns point to the interactivity of proactive control, as induced by a list-based PC manipulation, and reactive control, other evidence calls into question whether list-based PC manipulations consistently modulate proactive control. This evidence has stemmed from studies (like Hutchison, 2011) that aimed to unconfound ISPC and list-based PC (which were typically confounded prior to the discovery of the ISPC effect; see Bugg, 2012) to determine whether the list-based PC effect reflected a globally operating proactive control mechanism, and not the reactive mechanisms assumed to underlie the ISPC effect. For instance, Bugg, Jacoby, and Toth (2008) intermixed 50 %-congruent stimuli (e.g., red and blue) with other stimuli (e.g., green and white) that were either 75 % or 25 % congruent. This allowed the researchers to examine list-based PC effects in the Stroop task for 50 %-congruent items that were embedded in MC (.67) or MI (.33) lists, created by the congruency of the other stimuli. Bugg et al. found a nonsignificant, 13-ms list-based PC effect for 50 %-congruent items across lists, despite a significant 82-ms ISPC effect across lists (as assessed by comparing Stroop effects for the 75 %-congruent and 25 %-congruent items). This implied that, within confounded lists, the list-based PC effect was due to reactive mechanisms such as item-specific control of word-reading processes (Bugg, Jacoby, & Chanani, 2011) or the prediction of correlated responses (Melara & Algom, 2003; Schmidt & Besner, 2008; Schmidt, Crump, Cheesman, & Besner, 2007), and not to proactive control (see also Blais & Bunge, 2010).

Subsequent research has demonstrated, however, that this conclusion may be specific to list-based PC designs that use small sets (comprising two words and colors) of stimuli to establish the overall PC of the list (i.e., via 75 %- and 25 %-congruent items; Bugg, 2014; Bugg & Chanani, 2011; cf. Bugg, McDaniel, Scullin, & Braver, 2011; Hutchison, 2011). Most notably, Bugg (2014) demonstrated the conditions under which one can expect the engagement of proactive (top-down) control when list-based PC is manipulated (i.e., when participants cannot minimize interference on most trials via simple associative learning, as was possible in the studies of Bugg et al., 2008, and Blais & Bunge, 2010). Still, under these conditions, there was always an accompanying ISPC effect (when comparing the 75 %-congruent and 25 %-congruent items; e.g., Bugg, 2014, Exps. 1a and 2b). ISPC effects, thus, appear to be somewhat resistant to modulations of proactive control stemming from list-based PC manipulations alone.

The present approach: Use of congruency precues

The approach we adopted is based on prior studies by Goldfarb and Henik (2013), Bugg and Smallwood (2016), and Olsen, Powell, and Hutchison (under review), in which precues signaled the probability that an upcoming trial would be incongruent or congruent (cf. Correa et al., 2009; Gratton et al., 1992; Logan & Zbrodoff, 1982), rather than cueing specific items or locations (cf. Posner & Snyder, 1975; Posner, Snyder, & Davidson, 1980). This allows one to explicitly manipulate participants' expectations of the upcoming congruency, a type of information that can be used to proactively prepare attention in advance of stimulus onset. The more recent precueing studies have used relatively large stimulus sets (Bugg & Smallwood, 2016; Goldfarb & Henik, 2013; Olsen, Powell, and Hutchison, under review), rather than only two item sets, such that any precue benefits on incongruent trials may be attributed to the engagement of proactive control, rather than strategies such as strategically responding on the basis of the irrelevant dimension (Logan & Zbrodoff, 1979; see Bugg & Smallwood, 2016, for further discussion).

In Bugg and Smallwood's (2016) procedure, they used four color words on congruent and incongruent trials and either precued stimuli with the cues CONFLICTING or MATCHING or presented a noninformative, neutral cue (XXXXXXXXX). The cues were presented between 500 and 2,000 ms prior to the target. When the cues were 100 % valid, Bugg and Smallwood found a precue benefit that was significantly larger on congruent trials, as in prior studies (Correa et al., 2009; Gratton et al., 1992; Logan & Zbrodoff, 1982). The precue benefit for incongruent trials was also significant, but it was found selectively for the longest cue-to-stimulus interval (CSI), suggesting that it takes time for participants to prepare proactive control. In their third experiment, Bugg and Smallwood switched to 75 %-valid precues, allowing them to examine both the potential benefits and costs of precueing congruency. They found a Precue × Trial Type interaction at the longest CSI, such that, although the congruent reaction times (RTs) did not differ, incongruent RTs following the MATCHING cue were longer than those following the CONFLICTING cue, and marginally longer than those following the noninformative cue. This pattern suggests that participants proactively directed their attention away from word reading following the CONFLICTING or noninformative cues, relative to a MATCHING cue.

The evidence from recent precueing studies suggests that a congruency precue manipulation could work effectively in service of the present goal of testing the hypothesis regarding the interactivity of proactive and reactive control. One clear deviation from traditional list-based PC manipulations is that precues afford the control of attention via explicit information rather than via information that is implicitly acquired through experience in a given list (e.g., Blais, Harris, Guerrero, & Bunge, 2012; cf. Bugg et al., 2015). Accordingly, it might seem a foregone conclusion that participants would strategically use the precues to prepare attention, thereby reducing the influence of reactive control. However, an alternative prediction is possible. The predictive information described in the correlation account (Melara & Algom, 2003) might be so powerful that some tension exists between proactive efforts to, for example, divert attention away from word processing following a CONFLICTING cue, and the bottom-up capture and modulation of attention afforded by predictive (informative) words. Because of this tension, congruency precueing may be ineffective for MC and MI stimuli. However, if cueing reduces or eliminates the ISPC effect, this would suggest that the early, top-down suppression of word information via proactive control might override bottom-up attentional capture by highly informative words, and it would provide support for the interactivity of proactive and reactive control.

Experiment 1

The purpose of Experiment 1 was to provide an initial test for potentially reduced ISPC effects under conditions expected to enhance proactive control. In this experiment, precueing effects were examined in combination with the list-based PC manipulation more traditionally used to assess differences in proactive control. We adopted a design that has previously demonstrated both ISPC and list-based PC effects in the Stroop task (Bugg, 2014, Exp. 1a). In this design, each list contained two distinct sets of items (referred to below as *Set A* and *Set B*). Set A (e.g., RED, BLUE, WHITE, and PURPLE; see Table 1) comprised 75 %-congruent items (termed *PC75*) in the MC list and 25 %-congruent items (termed *PC25*) in the MI list. Set B (e.g., PINK, GREEN, BLACK, and YELLOW; see Table 1) comprised 50 %-congruent items (*PC50*), and this set was embedded within the MC and MI lists. Combining the two sets yielded lists that were 67 % or 33 % congruent, respectively.

To examine the predicted change in the size of the ISPC effect as a function of precue condition, we compared the

Table 1 Frequencies of trial types presented in the informative and noninformative precue conditions of Experiment 1

List Type	Item Set	Word	Color			
			Red	Blue	White	Purple
Mostly Incongruent	A	RED	**9**	9	9	9
		BLUE	9	**9**	9	9
		WHITE	9	9	**9**	9
		PURPLE	9	9	9	**9**
			Pink	Green	Black	Yellow
	B	PINK	**9**	3	3	3
		GREEN	3	**9**	3	3
		BLACK	3	3	**9**	3
		YELLOW	3	3	3	**9**
			Red	Blue	White	Purple
Mostly Congruent	A	RED	**27**	3	3	3
		BLUE	3	**27**	3	3
		WHITE	3	3	**27**	3
		PURPLE	3	3	3	**27**
			Pink	Green	Black	Yellow
	B	PINK	**9**	3	3	3
		GREEN	3	**9**	3	3
		BLACK	3	3	**9**	3
		YELLOW	3	3	3	**9**

In this table, RED, BLUE, WHITE, and PURPLE serve in the roles of PC25 (top) and PC75 (bottom) Set A items, whereas PINK, GREEN, BLACK, and YELLOW serve in the role of PC50 Set B items. The frequencies of trial types were identical in the informative and noninformative precue conditions. **Bold** numbers represent congruent trials extent to which Stroop interference was reduced for MI (PC25) items relative to MC (PC75) items in a noninformative precue condition relative to an informative precue condition, by analyzing Set A items. In the informative precue condition, 100 %-valid precues (either MATCHING or CONFLICTING) were shown prior to each (congruent or incongruent, respectively) trial, following Bugg and Smallwood (2016), whereas in the noninformative precue condition, a string of Xs was presented prior to each trial. A smaller ISPC effect (i.e., a smaller reduction in interference for MI relative to MC items) was expected in the informative precue condition than in the noninformative precue condition. In other words, precueing participants to direct attention toward or away from word reading should reduce or eliminate the tendency of distractor words themselves to capture or deflect attention.

An advantage of using the present design is that it also enables an examination of the effects of precueing on list-based PC effects (i.e., the reduction in interference for MI as compared to MC lists), independent of item-specific influences, by examining performance on the PC50 items (i.e., restricting analyses to Set B). List-based PC effects, like ISPC effects, depend on learning correlations between the irrelevant words and the to-be-named colors. If the use of informative precues disrupts learning about the PC of the PC75 and PC25 items, as predicted, then the list-based PC effect on PC50 items should be attenuated or nonsignificant in the informative precue condition. That is, if one does not learn about the list bias (PC) via processing the relationship between words and colors for PC75/PC25 items, then interference should be equivalent for the PC50 items across MC and MI lists. Therefore, we presented noninformative and informative precues across separate blocks of trials to demonstrate (1) the standard list-based PC effect in noninformative blocks and (2) a reduction of this effect in informative precue blocks.

To summarize, we hypothesized that precueing congruency would attenuate both ISPC and list-based PC effects. Predirecting attention toward or away from word reading via precues should undermine the tendency of specific words to attract or deflect attention, and also undermine any effect that the overall list context would normally have on the use of proactive versus reactive forms of control.

Method

Participants Consistent with Bugg and Smallwood (2016), who tested between 19 and 24 participants in their Experiments 1–3, we ran 24 participants in each of our lists for this study. Forty-eight undergraduates participated for course credit or $10. The participants were native English speakers with normal or corrected vision and color vision. Half of the participants were randomly assigned to each of the MC and MI conditions.

Design We used Bugg and Smallwood's (2016) informative precue (MATCHING vs. CONFLICTING) and noninformative precue (XXXXXXXXX) conditions. A 2 × 2 × 2 × 2 mixed-subjects design examined Precue (noninformative vs. informative), Trial Type (congruent vs. incongruent), and Item Type (PC25/PC75 vs. PC50) as within-subjects factors and List-Based PC (MC vs. MI) as a between-subjects factor. The precues were 100 % valid in the informative condition, and the order in which the informative and noninformative precue conditions were administered was counterbalanced across subjects.

Materials Four words and their corresponding colors composed one set of items (e.g., pink, green, black, and yellow), and four different words and their corresponding colors (e.g., red, blue, white, and purple) composed a second set of items. One set was used to create the overall list PC (see Table 1). We refer to this set as the *PC75* or *PC25* set, because the ISPC of the items within that set was either 75 % or 25 % congruent. We refer to the second set of items as the *PC50* items because these items were 50 % congruent. Combining the first with the second set of items yielded lists that were either MC (PC75 + PC50 items = 67 % congruent list) or MI (PC25 + PC50 items = 33 % congruent list; see Table 1). The assignment of word/color sets to the PC75/PC25 and PC50 conditions was counterbalanced across subjects.

Procedure Informed consent was obtained. Participants were tested individually in a small room with the experimenter present and were instructed that the goal was to name the font color in which the stimulus was displayed (and not the word itself) as quickly as possible while maintaining a high level of accuracy. Stimuli were presented through use of the E-Prime software (Schneider, Eschman, & Zuccolotto, 2002), and a microphone connected to a PST serial response box captured response latencies. In the informative precue condition, participants were told that the precue MATCHING meant that the font color would match the word for the next stimulus, and the precue CONFLICTING meant the font color would not match the word for the next stimulus. They were also instructed that it was very important that they try their best to use the information provided by the precues, and they were given the example of using the CONFLICTING precue to ready themselves to ignore the distracting word. In the noninformative condition, participants were told that a string of Xs would appear, followed by the stimulus.

Each participant completed three blocks of trials that contained informative precues and three blocks that contained noninformative precues, and these blocks were counterbalanced such that equal numbers of participants completed the informative and noninformative blocks in each order. Each block consisted of 72 trials, with the proportions of congruent and incongruent trials depending upon list. Rest breaks were given between blocks.

Prior to each block, participants completed a small set of practice trials. On practice and experimental trials, the precue was presented for 1,400 ms and followed by a blank screen for 100 ms. Following this, the Stroop stimulus was presented on a gray screen and remained there until a microphone response was detected by the computer. The researcher, seated next to the participant, then coded the participant's response using a keyboard on which the keys were labeled with colored stickers. Following the coded response, a 1,000-ms intertrial interval preceded the onset of the next precue.[1] Trials on which the microphone was tripped by an irrelevant noise (e.g., a cough) or on which the response was not perceptible were coded as scratch trials and not analyzed.

Results

The alpha level was set at .05, and partial eta-squared (η_p^2) is reported as the measure of effect size. Error trials were excluded from the RT analysis. RT data were treated as in previous studies (Hutchison 2007, 2011), with RTs less than 50 ms or greater than 2,000 ms being removed, excluding less than 0.01 % of the trials. Next, a separate mean and standard deviation were computed for congruent and incongruent trials for each participant. We used the nonrecursive outlier removal procedure, suggested by Van Selst and Jolicœur (1994), in which the criterion for outlier removal shifts on the basis of the number of valid observations per condition. This method reduces the sample size bias present in other outlier removal procedures (see Van Selst & Jolicœur, 1994) and removed 2.6 % of the present correct RTs. Other than those reported, no other main effects or interactions were significant in this or the subsequent experiment. Following prior studies that had employed the design used here (though without the precue manipulation; Bugg, 2014; cf. Blais & Bunge, 2010; Bugg et al., 2008), we conducted separate ANOVAs for the PC75/PC25 items and the PC50 items. A 2 (Precue) × 2 (Proportion Congruency) × 2 (Trial Type) mixed-subjects ANOVA was performed on the RT and error rate data.[2]

PC75/PC25 items Means and standard errors for the PC75 and PC25 items are shown in Fig. 1. We first examined our hypothesis that ISPC effects would be reduced when using informative precues. As predicted, a three-way interaction between precue, item PC, and trial type was found, $F(1, 46) = 15.27$, $MSE = 500$, $p < .001$, $\eta_p^2 = .249$. To decompose this interaction, we examined the Item PC × Trial Type interaction (i.e., the ISPC effect) separately for the noninformative and informative precue conditions. The pattern was as predicted. As is shown at the top of Fig. 1, in the noninformative precue condition, the ISPC effect was robust, $F(1, 46) = 19.25$, $MSE = 1,439$, $p < .001$, $\eta_p^2 = .295$, with reduced Stroop effects for the PC25 items ($M = 73$) as compared to the PC75 items ($M = 141$). By contrast, in the informative precue condition, the ISPC effect was attenuated and not statistically significant, $F(1, 46) = 1.01$, $MSE = 1,811$, $p = .319$, $\eta_p^2 = .022$. Stroop effects were again smaller for the PC25 items ($M = 153$) than for the PC75 items ($M = 170$), but the difference was only a nonsignificant 17 ms (vs. 68 ms in the noninformative precue condition).

In addition to evidence supporting the primary hypothesis, we found that RTs were faster following the informative precue ($M = 600$, $SE = 11$) than following the noninformative precue ($M = 661$, $SE = 12$), and faster for congruent trials ($M = 563$, $SE = 11$) than for incongruent trials ($M = 698$, $SE = 13$). These observations were confirmed by main effects of precue, $F(1, 46) = 83.66$, $MSE = 2,115$, $p < .001$, $\eta_p^2 = .645$, and trial type, $F(1, 46) = 316.02$, $MSE = 2,750$, $p < .001$, $\eta_p^2 = .873$. In addition, a two-way interaction between item PC and trial type

[1] This coding procedure is identical to that of Bugg and Smallwood (2016). In principle, experimenters could take longer to code responses when trial stimuli mismatch the precue and this could effectively influence the response–stimulus interval for the next trial. However, with randomized precues, this should not systematically affect performance in any condition. Indeed, Bugg and Smallwood demonstrated in all three of their experiments that Precue × Trial Type interactions were present in participants' RTs, but not in the experimenters' coding RTs. Thus, the effects were not caused by the experimenter-coding RTs.

[2] In an initial ANOVA of PC75/PC25 items that included precue counterbalance order, no overall effect of precue order emerged ($p = .583$, $\eta_p^2 = .007$), and the counterbalance order did not enter into any interactions with other variables (all ps > .135, η_p^2s < .050). Precue order was therefore not included in any further analyses. For the PC50 items, when including precue counterbalance order, there was a significant Precue Order × Trial Type interaction, $F(1, 44) = 7.909$, $MSE = 1,612$, $p < .007$, $\eta_p^2 = .152$, such that Stroop effects were larger when informative precues occurred first rather than last. However, precue order did not enter into any other interactions (all ps > .466, all η_p^2s < .013) and was therefore not included in further analyses. The significance of all effects reported below remained unchanged, regardless of whether counterbalance order was included in the analyses.

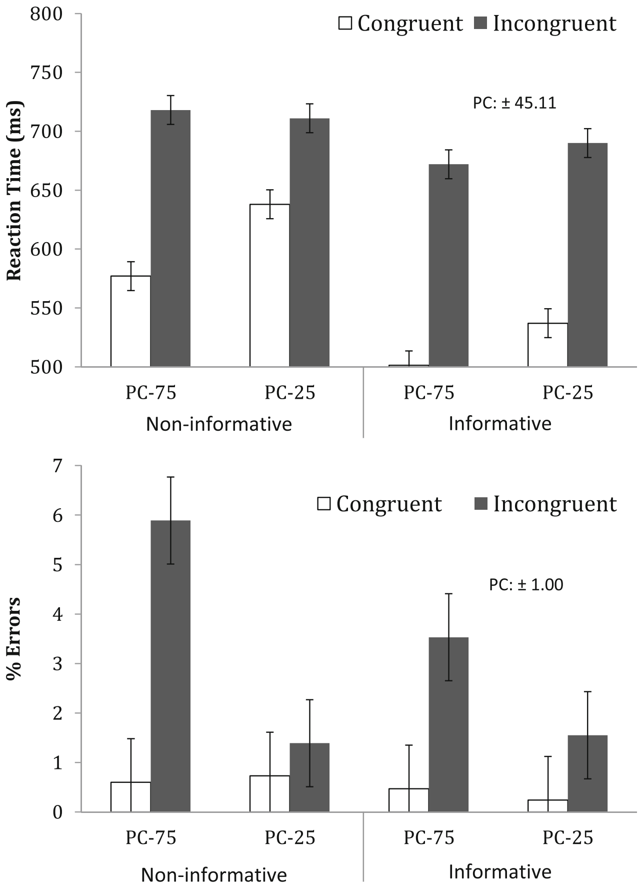

Fig. 1 Mean reaction times (top) and percent errors (bottom) for PC75/PC25 items in the noninformative precue and informative precue conditions in Experiment 1, as a function of item proportion congruency (PC) and trial type. Error bars represent 95 % confidence intervals (CIs) based on the pooled within-group error terms (Masson & Loftus, 2003). CIs for the PC factor are shown separately

indicated an overall ISPC effect, $F(1, 46) = 7.96$, $MSE = 2,750$, $p < .01$, $\eta_p^2 = .148$. Interference was reduced for the PC25 items ($M = 113$) as compared to the PC75 items ($M = 156$). Finally, we obtained a Trial Type × Precue interaction, $F(1, 46) = 74.31$, $MSE = 500$, $p < .001$, $\eta_p^2 = .618$, such that Stroop effects were larger in the informative condition ($M = 162$ ms) than in the noninformative condition (107 ms). Examination of Fig. 1 shows that this increase in Stroop effects in the informative condition was due to the informative precue having a larger benefit on congruent ($M = 89$ ms) than on incongruent ($M = 33$ ms) trials, though both were significant according to planned comparisons [$F(1, 46) = 112.28$, $MSE = 1,676$, $p < .001$, $\eta_p^2 = .709$; $F(1, 46) = 27.64$, $MSE = 939$, $p < .001$, $\eta_p^2 = .375$, for congruent and incongruent trials, respectively].

For error rates, the predicted three-way interaction between precue, item PC, and trial type approached significance, $F(1, 46) = 3.44$, $MSE = 7$, $p = .07$, with a pattern similar to that found for RTs, such that a significant 4.6 % ISPC effect, $F(1, 46) = 9.58$, $MSE = 13$, $p < .004$, $\eta_p^2 = .172$, in the noninformative precue condition was numerically reduced to a marginally significant 1.8 % in the informative precue condition, $F(1, 46) = 2.99$, $MSE = 6$, $p = .09$, $\eta_p^2 = .061$. In addition, we found main effects of item PC, $F(1, 46) = 10.86$, $MSE = 12$, $p < .003$, $\eta_p^2 = .191$, and trial type, $F(1, 46) = 26.05$, $MSE = 12$, $p < .001$, $\eta_p^2 = .362$, and an interaction between these two factors indicating an ISPC effect, $F(1, 46) = 9.91$, $MSE = 12$, $p < .003$, $\eta_p^2 = .177$. Stroop effects were reduced for PC25 items ($M = 1.0$ %) as compared to the PC75 items ($M = 4.2$ %).

PC50 items Means and standard errors for PC50 items presented within the MC and MI lists are shown in Fig. 2. We first examined our hypothesis that list-based PC effects would be reduced when using informative precues. As predicted, the three-way Precue × List PC × Trial Type interaction was significant, $F(1, 46) = 10.90$, $MSE = 630$, $p = .002$, $\eta_p^2 = .192$. To decompose the interaction, we examined the List PC × Trial Type interaction separately for the noninformative and

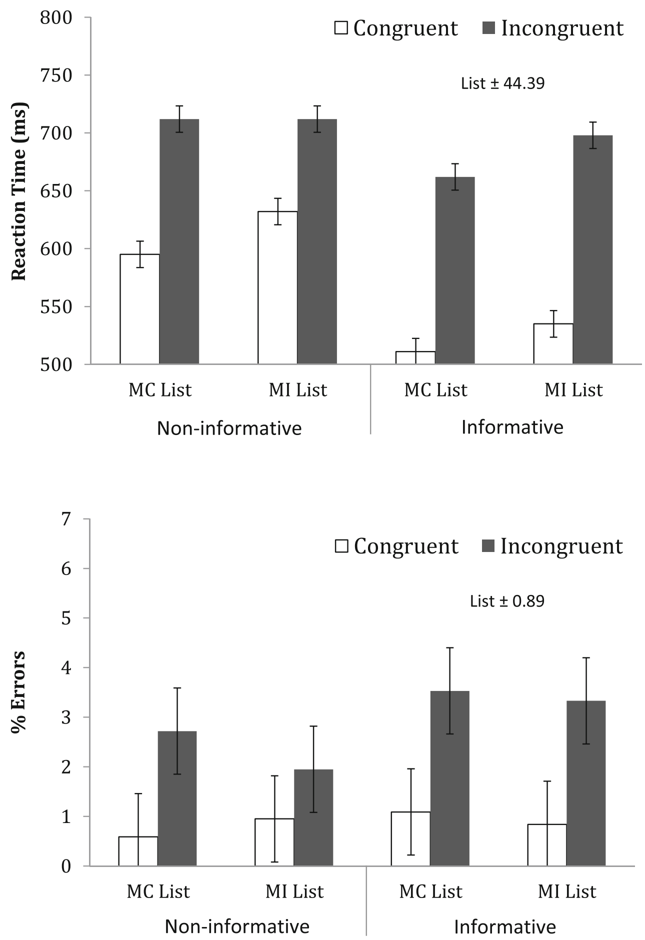

Fig. 2 Mean reaction times (top) and percent errors (bottom) for 50 %-congruent (PC50) items in the noninformative precue and informative precue conditions of Experiment 1, as a function of list proportion congruency and trial type. Error bars represent 95 % confidence intervals (CIs) based on the pooled within-group error terms (Masson & Loftus, 2003). CIs for the List factor are shown separately

informative precue conditions. As is shown in Fig. 2, for the noninformative precue condition, the List PC × Trial Type interaction was significant, indicating a list-based PC effect, $F(1, 46) = 7.29$, $MSE = 1{,}070$, $p < .01$, $\eta_p^2 = .137$. Stroop effects were reduced for PC50 items in the MI list ($M = 81$ ms) relative to PC50 items in the MC list ($M = 117$ ms). In contrast, in the informative precue condition, the List PC × Trial Type interaction was not significant, $F < 1$, $\eta_p^2 = .013$. In fact, the pattern was in the opposite direction from the standard list-based PC effect, with nominally larger Stroop effects for PC50 items in the MI list ($M = 163$ ms) than for PC50 items in the MC list ($M = 151$ ms; see Fig. 2).

In addition to evidence supporting the primary hypothesis, we found that RTs were faster in the informative precue condition ($M = 601$, $SE = 11$) than in the noninformative precue condition ($M = 663$, $SE = 12$), and for congruent ($M = 568$, $SE = 11$) than for incongruent ($M = 696$, $SE = 12$) trials, as confirmed by main effects of precue, $F(1, 46) = 82.08$, $MSE = 2{,}200$, $p < .001$, $\eta_p^2 = .641$, and trial type, $F(1, 46) = 429.65$, $MSE = 1{,}821$, $p < .001$, $\eta_p^2 = .903$. As was the case for the PC75/PC25 items, we also observed a Precue × Trial Type interaction, $F(1, 46) = 64.40$, $MSE = 630$, $p < .001$, $\eta_p^2 = .583$, such that Stroop effects were larger following the informative precue (157 ms) than following the noninformative precue (99 ms). Again, this was due to a larger precue benefit for congruent ($M = 90$ ms) than for incongruent ($M = 32$ ms) trials, though again both benefits were significant on the basis of planned comparisons [$F(1, 46) = 107.75$, $MSE = 1{,}821$, $p < .001$, $\eta_p^2 = .701$, and $F(1, 46) = 24.75$, $MSE = 1{,}010$, $p < .001$, $\eta_p^2 = .350$, respectively]. The overall interaction between list PC and trial type was not significant, $F < 1$.

For error rates, only the main effect of trial type was significant, $F(1, 46) = 23.05$, $MSE = 8$, $p < .001$, $\eta_p^2 = .334$, with more errors on incongruent ($M = 3.1$ %, $SE = 0.5$) than on congruent ($M = 0.5$ %, $SE = 0.1$) trials.

Discussion

The key finding of Experiment 1 was the modulation of item- and list-based PC effects by precue type. When a noninformative precue was shown prior to each stimulus, the typical ISPC effects were found for the PC75/PC25 items. In addition, replicating previous research, a list-based PC effect was found on PC50 items for which ISPC was controlled (Bugg, 2014; Bugg & Chanani, 2011; Hutchison, 2011). The size of the list-based PC effect replicated prior studies that did not employ a precueing manipulation but that did manipulate PC identically (Bugg, 2014, Exp. 1a) or in a very similar fashion (Bugg & Chanani, 2011) to the present study. The data from the noninformative precue condition indicated that biasing the PC of a list via a subset of items (PC75 or PC25) leads to shifts in control not only at the item-specific level (as indicated by the item-PC effect for the PC75/PC25 items), but also at the list (global) level (as indicated by the list-PC effect for the PC50 items). Of most importance, the novel finding from the present study was that these shifts (reflected by the PC effects) were significantly attenuated when a 100 %-valid, informative precue was presented prior to each stimulus. As predicted, the ISPC effect (for the PC75/PC25 items) was less robust in the informative precue condition, in which we expected participants to engage proactive control in response to the precues. The difference in Stroop effects between the MC and MI items (i.e., ISPC effect) was only 17 ms in the informative precue condition, as compared to 68 ms in the noninformative precue condition. Similarly, as predicted, the list-based PC effect (for the PC50 ms) was not found in the informative precue condition, and was actually reversed (−12 ms), relative to the noninformative precue condition, wherein the effect was significant (36 ms more interference for PC50 items in the MC than in the MI list). The attenuation of these PC effects is consistent with the view that use of the precues reduced the influence of the correlations between irrelevant words and PC levels (e.g., stimulus–attention associations or stimulus–response associations; Bugg & Crump, 2012; Jacoby et al., 2003; Melara & Algom, 2003). Specifically, because the precues themselves directed attention either toward or away from word reading, participants appeared to rely less on the reactive information carried by the Stroop words in the informative precue condition.

These patterns provide support for the view that precueing congruency can enhance participants' ability to selectively attend to color over word information. Examining the three-way interactions of cue type, PC, and trial type from a slightly different perspective than that described above provides additional evidence. As can be seen in Figs. 1 and 2, similar to Goldfarb and Henik (2013, Exp. 2), the precue benefit (i.e., the difference between the informative and noninformative precue conditions) was largest for the infrequent trial type within a particular condition (e.g., for incongruent items in MC lists relative to incongruent items in MI lists), likely because amplification or attenuation of word processing, respectively, was nearing a maximal level due to experience alone (within each list). This evidence also points toward the interactivity of proactive and reactive control mechanisms. For example, with an MI list, the experience of frequently encountering incongruent trials may in and of itself lead to a boost in control (e.g., Botvinick et al., 2001; Braver et al., 2007). As such, participants may not have much room to further heighten control when a CONFLICTING cue is shown (Goldfarb & Henik, 2013; cf. Bugg, Diede, Cohen-Shikora, & Selmeczy, 2015). By contrast, in the MC list conflict is infrequent, and the expectation is for trials not to be interfering. As such, the presentation of a CONFLICTING cue carries highly valuable information, and the data suggest strong benefits of exerting proactive control to minimize interference in this context (e.g., an average precue benefit of 48 ms on incongruent trials in the

MC list, as compared to an average 17-ms benefit in the MI list).

Experiments 2a and 2b

Consistent with our predictions, 100 %-valid precues eliminated the ISPC effect in Experiment 1. This aligns with proactive and reactive control interactivity. Specifically, why should an item draw attention toward or away from word reading if a precue has already done this? An important question is whether this interactivity is limited to the use of 100 %-valid precues, as in Experiment 1 (see also Bugg & Smallwood, 2016, Exps. 1, 2, and 4; Goldfarb & Henik, 2013). As was argued by Bugg and Smallwood, with a 100 %-valid MATCHING cue it is likely that participants intentionally switch to a word-reading strategy. In this case, an MC item should not draw additional attention toward word reading. Evidence that (at least some) participants strategically switched to word reading in Experiment 1 comes from the finding that the Stroop effect was larger following the informative precue and that this increased Stroop effect was mostly caused by a speedup in congruent RTs following the MATCHING cue (see Figs. 1 and 2).

It was therefore of interest in Experiment 2 to examine whether ISPC effects would also be attenuated when the upcoming congruency was probabilistic, rather than certain. In this case, participants could not use MATCHING precues to switch tasks from color naming to word reading. Instead, probabilistic precues should affect the allocation of attention toward or away from distractor words within the color-naming task. Critically, using probabilistic cues allows one to calculate Stroop effects (and ISPC effects) separately following each precue. That is, we examined whether Stroop and ISPC effects were reduced when participants prepared for conflict, relative to when they expected congruency (entirely within an informative precue condition). This contrasts with Experiment 1, wherein Stroop effects referred to a contrast between congruent trials that followed a MATCHING cue and incongruent trials that followed a CONFLICTING cue, and such Stroop effects were compared across the informative and noninformative precue conditions. Therefore, in Experiment 2 we eliminated the noninformative condition. An additional benefit was that doing so allowed us to correct for potential differences in alerting properties between linguistic and nonlinguistic cues (Jonides & Mack, 1984).

The second and third goals of Experiment 2 were to disconnect the precues from the critical Stroop stimuli and the overall list PC, respectively. For congruent trials in Experiment 1, the precue always combined with a particular distractor to dictate a particular response (e.g., MATCHING + word BLUE = "blue" response), raising the possibility that participants learned compound precue + stimulus + response relations (see Forrest, Monsell, & McLaren, 2014; see also Logan & Bundesen, 2003). Also, in Experiment 1 the MI list contained many more CONFLICTING than MATCHING cues, and the MC list contained many more MATCHING than CONFLICTING cues. This would lead to more informational value for CONFLICTING cues within MC lists, and for MATCHING cues within MI lists (see also Goldfarb & Henik, 2013, Exp. 2, for a similar issue). In Experiment 2 we equated the informational values of both cues, while maintaining an overall list PC of 50 %.

We were able to address both of these goals by using a precue method recently reported by Olsen, Powell, and Hutchison (under review), in which they used 80 %-valid EASY and HARD precues to signal *likely congruent* versus *likely incongruent*, respectively. In Experiment 2a, we rendered these precues nondiagnostic for a set of critical items, such that a particular critical stimulus (e.g., BLUE in red font) was equally likely to be preceded by an EASY or HARD cue. Instead, precue validity was established through the use of filler items (e.g., WHITE and GREEN) that were 100 %-congruent following EASY precues and 100 % incongruent following HARD precues. This disconnected the precues from the critical stimuli themselves, allowing us to test whether precue effects "transfer" to items for which the precues are actually nondiagnostic (similar to how we tested whether list-PC effects could be found for items that were 50 % congruent in Exp. 1). This also allowed us to examine the relative benefits/costs of EASY and HARD precues within a list in which they appeared equally frequently, and thus carried the same informational value. The key hypothesis, following from the predicted interactivity of proactive and reactive control, was that both the Stroop and ISPC effects should be attenuated following a HARD as compared to an EASY precue. To preview our results, the Stroop and ISPC effects were indeed reduced following a HARD precue. For Stroop effects, this was demonstrated by a significant two-way interaction between trial type and precue. For ISPC effects, this was demonstrated by a three-way interaction between trial type, precue, and item PC that approached significance in Experiment 2a, reached significance in Experiment 2b, and, not surprisingly, was significant when both experiments were combined.

Method

Participants Because (1) Olsen, Powell, and Hutchison (under review, Exp. 1) found a Cue × Stroop interaction with 64 participants using a probabilistic-cuing method similar to the one in the present study and (2) the present experiment included an additional ISPC variable, we planned to test 100 participants in Experiment 2a. However, we only completed 79 participants by the end of the semester. Experiment 2b was a direct replication of Experiment 2a, but with a larger sample size. We had to discard the data from several early participants due to microphone problems; therefore, we ran a total of 115 participants to ensure we had a final sample of at least 100.

Both male and female introductory psychology students participated in Experiments 2a and 2b for partial fulfillment of course credit. All participants were native English speakers and had normal or corrected-to-normal color vision. The data from 15 participants were not analyzed because of microphone problems (three participants in Exp. 2a, 12 in Exp. 2b) or over 30 % overall task errors (one participant in Exp. 2a, none in Exp. 2b), leaving data from 75 and 103 participants in Experiments 2a and 2b, respectively.

Materials The Stroop stimuli consisted of six different color words (RED, BLUE, YELLOW, BLACK, GREEN, and WHITE) and their corresponding colors. These words were split into critical and filler items. The 156 total trials contained 96 critical trials and 60 filler trials. The frequencies of each trial type as a function of precue are shown in Table 2. The four critical color words were shown 24 times each and consisted of two PC67 (MC) words (e.g., red and blue) and two PC33 (MI) words (e.g., yellow and black). The PC67 words were presented in their own color 67 % of the time (e.g., RED presented in red font) and in the other color 33 % of the time (e.g., RED presented in blue font). PC33 words received the opposite congruency assignments. The PC67 and PC33 item sets were counterbalanced across subjects. For these critical items, the cues were actually nondiagnostic. Specifically, each critical color word was shown 12 times following the precue EASY and 12 times following the precue HARD. In order to establish the validity of these precues, we included two filler color words (GREEN and WHITE) presented 30 times each with 100 %-valid precues (e.g., 15 congruent trials preceded by the cue EASY and 15 incongruent trials preceded by the cue HARD). Across all stimuli, the overall list PC was .50 and the precue validity was .692 [(48 valid critical + 60 valid filler)/156 total].

Design and procedure We used a 2 (Precue: easy/hard) × 2 (Item PC: MC/MI) × 2 (Trial Type: congruent/incongruent) within-subjects design. All participants provided informed consent and were tested individually. Stimuli were again presented using the E-Prime software (Schneider et al., 2002), and a microphone connected to a PST response box captured response latencies. The experimenter coded responses using a keyboard labeled with colored stickers.

Instructions first appeared on screen and were paraphrased by the experimenter. The experimenter informed participants that they would see a series of words presented one at a time and that their goal was to name the font color, not the word itself. The experimenter also told them that each trial was preceded by one of two cues, EASY or HARD, which were indicative of the potential congruency of the upcoming stimulus (congruent or incongruent, respectively). Participants were informed that they should use these cues to maximize their performance. These precues were 69.2 % valid and were accompanied by a point value to provide additional incentive for attending to the cues, because early pilot subjects had reported ignoring the cues (see also Logan & Zbrodoff, 1982). Participants were told that EASY trials were worth one point and HARD trials were worth ten points, and that they should try to maximize their point total (see Bugg et al., 2015, for evidence that point incentives can be effective in enhancing precue use in the Stroop task).

On each trial, participants were first presented with an EASY or HARD cue for 750 ms, followed by a blank screen for 1,500 ms. The target color word then appeared for 2, 500 ms or until a response. After the response had been coded by the experimenter, a blank 1,000-ms intertrial interval preceded the next trial. Participants first completed 18 practice trials to familiarize themselves with the procedure. Each practice trial was followed by feedback (CORRECT or INCORRECT) as well as the total points earned. The Stroop task itself consisted of 156 total trials, with two self-paced rest breaks presented every 52 trials. During the experiment no feedback was provided, and the total points earned were only shown during rest breaks.[3]

Results

The trimming procedures were identical to those in the previous experiment, and eliminated 2.9 % and 2.4 % of trials in Experiments 2a and 2b, respectively. The alpha level remained at .05. Critical-item RTs and errors were analyzed using a 2 (Precue) × 2 (Item PC) × 2 (Trial Type) × 2 (Experiment) mixed ANOVA with the repeated measures of precue, item PC, and trial type and the between-group variable of experiment. These data are shown in Figs. 3 and 4. For RTs, we first examined our hypotheses that both Stroop effects and ISPC effects would be reduced following the *hard* cue relative to the *easy* cue. The results confirmed both of these hypotheses. First, the Stroop effect was smaller following the HARD precue (M = 84 ms) than following the EASY precue (M = 100 ms), as evidenced by a Precue × Trial Type interaction, $F(1, 176) = 18.750$, $p < .001$, $\eta_p^2 = .096$. In contrast to Experiment 1 (but consistent with Bugg & Smallwood's, 2016, use of probabilistic precues in their Exp. 3), there was no effect of precue on congruent RTs (−2 ms), whereas incongruent RTs were 13 ms faster following the HARD precue.

[3] We also tested WMC using the automated version of the OSPAN task (Unsworth, Heitz, Schrock, & Engle, 2005), and this factor did indeed moderate the effect of precuing on ISPC effects. However, we elected to eliminate this variable from our analyses due to a possible speed–accuracy trade-off involving WMC. We are currently conducting additional research on possible interactions with working memory by directly manipulating cognitive load.

Table 2 Frequencies of trial types presented following the easy and hard precue conditions of Experiment 2

Cue	Item Type	Word	Color					
			Red	Blue	Yellow	Black	White	Green
Easy (01 pts)	Mostly Congruent	RED	**9**	3				
		BLUE	3	**9**				
	Mostly Incongruent	YELLOW			**3**	9		
		BLACK			9	**3**		
	Filler	WHITE					**15**	0
		GREEN					0	**15**
Hard (10 pts)	Mostly Congruent	RED	**9**	3				
		BLUE	3	**9**				
	Mostly Incongruent	YELLOW			**3**	9		
		BLACK			9	**3**		
	Filler	WHITE					**0**	15
		GREEN					15	**0**

The frequencies of trial types for mostly congruent and mostly incongruent critical items did not vary as a function of precue conditions, whereas the frequencies for filler trials are 100 % precue dependent. **Bold** numbers represent congruent trials

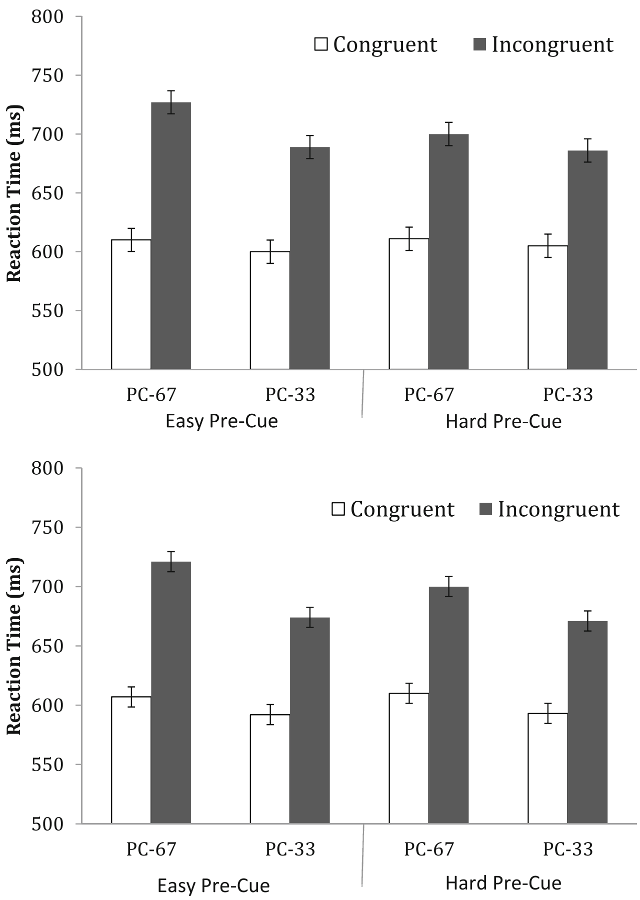

Fig. 3 Mean reaction times for the easy and hard precue conditions in Experiments 2a (top) and 2b (bottom), as a function of item proportion congruency (PC) and trial type. Error bars represent 95 % confidence intervals for the pooled mean-squared error terms (see Masson & Loftus, 2003)

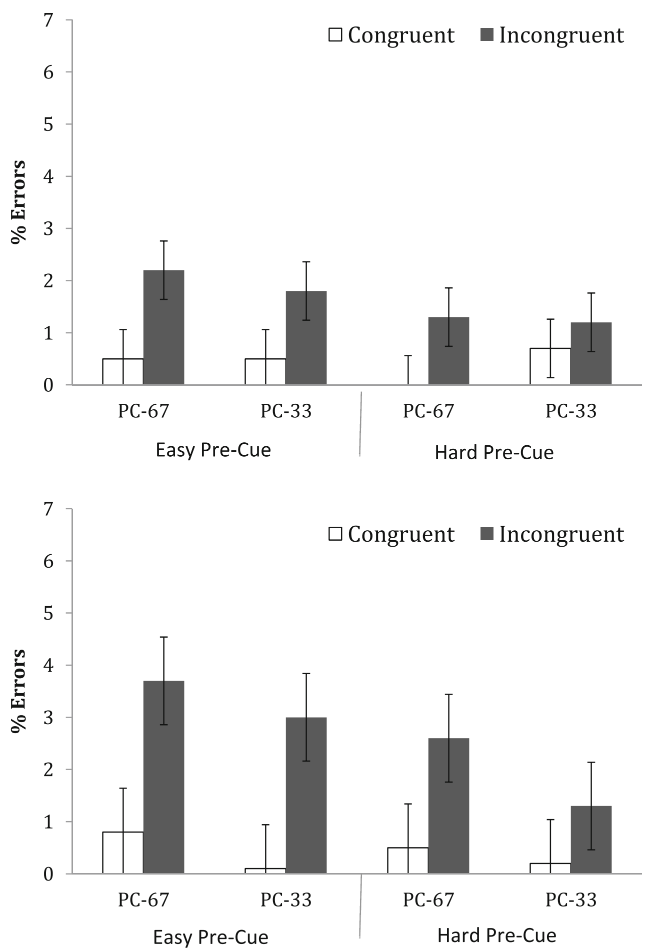

Fig. 4 Mean percent errors for the easy and hard precue conditions in Experiments 2a (top) and 2b (bottom), as a function of item proportion congruency (PC) and trial type. Error bars represent 95 % confidence intervals for the pooled mean-squared error terms (see Masson & Loftus, 2003)

Second, similar to our finding in Experiment 1 that informative precues eliminated the ISPC effect, we found a three-way Precue × Item PC × Trial Type interaction, $F(1, 176) = 7.623$, $p = .006$, $\eta_p^2 = .0042$. To clarify this three-way interaction, we examined the simple Item PC × Trial Type interactions (i.e., ISPC effects) separately following EASY and HARD precues. Following EASY precues, a robust ISPC effect was observed, $F(1, 176) = 21.299$, $p < .001$, $\eta_p^2 = .108$, with 29-ms larger Stroop effects for PC67 items (115 ms) than PC33 items (86 ms). However, this ISPC effect was nonsignificant following the HARD precues, $F(1, 176) = 3.781$, $p = .053$, $\eta_p^2 = .021$, with similar-sized Stroop effects for PC67 items (89 ms) and PC33 items (80 ms). Furthermore, this three-way interaction did not depend on experiment [$F(1, 176) = 0.000$, $p = .985$, $\eta_p^2 = .000$, for the four-way interaction with experiment].

In addition to the hypotheses tested above, we found that people responded more quickly to trials that followed a HARD ($M = 647$ ms, $SE = 6$) rather than an EASY ($M = 653$ ms, $SE = 6$) precue, to congruent ($M = 604$ ms, $SE = 6$) than to incongruent ($M = 696$ ms, $SE = 7$) trials, and to PC33 ($M = 639$ ms, $SE = 6$) than to PC67 ($M = 661$ ms, $SE = 7$) stimuli. These observations were confirmed by main effects for precue, $F(1, 176) = 10.143$, $p < .002$, $\eta_p^2 = .054$; PC, $F(1, 176) = 79.007$, $p < .001$, $\eta_p^2 = .310$; and trial type, $F(1, 176) = 605.251$, $p < .001$, $\eta_p^2 = .775$. Furthermore, an ISPC effect was observed, in the form of an Item PC × Trial Type interaction, $F(1, 176) = 19.204$, $p < .001$, $\eta_p^2 = .098$, such that the Stroop effect was greater for PC67 ($M = 102$ ms) than for PC33 ($M = 83$ ms) items. Finally, a Precue × Item PC interaction occurred, $F(1, 176) = 10.592$, $p < .001$, $\eta_p^2 = .057$. Whereas PC33 RTs remained the same across precues, participants responded to PC67 stimuli more quickly following a HARD precue ($M = 655$ ms) than following an EASY precue ($M = 666$ ms). No effects involving experiment approached significance (all $ps > .05$, all η_p^2s $< .022$).

Overall, errors were quite low in this experiment ($M = 1.3$ %). In terms of the critical hypotheses, the error analyses confirmed that Stroop effects were larger following the EASY precue ($M = 2.2$ %) than following the HARD precue ($M = 1.3$ %), as revealed by a Precue × Trial Type interaction, $F(1, 176) = 7.461$, $p = .007$, $\eta_p^2 = .041$. The predicted three-way interaction with item PC, which was obtained in RTs, was not significant in errors, $F(1, 176) = 1.070$, $p = .302$, $\eta_p^2 = .006$.

In addition, participants made fewer errors on trials that followed a HARD ($M = 1.0$ %) rather than an EASY ($M = 1.6$ %) precue, and fewer errors for congruent ($M = 0.4$ %) than for incongruent ($M = 2.1$ %) trials. These observations were confirmed by main effects of precue, $F(1, 176) = 7.461$, $p = .007$, $\eta_p^2 = .041$, and trial type, $F(1, 176) = 40.725$, $p < .001$, $\eta_p^2 = .188$. No other effects reached significance (all $ps > .05$, all η_p^2s $< .021$).

Discussion

The two main findings from Experiments 2a and 2b were predicted and expand our understanding of the impact of precues on Stroop and ISPC effects. First, Stroop effects were reduced following the HARD relative to the EASY precues. Second, we replicated the Precue × ISPC interaction obtained in Experiment 1. These findings are discussed in turn.

The predicted Precue × Trial Type interaction supports our hypothesis that participants would use the HARD precue to exert greater proactive control over word reading, reducing the Stroop effect. Importantly, this pattern differed from that in Experiment 1, in which the informative precues increased Stroop effects relative to the noninformative precues mainly by speeding congruent responses following a MATCHING precue. In contrast, in Experiment 2, congruent responding was unaffected by the precue, whereas incongruent responses were faster following the HARD than following the EASY precue. This is the pattern one would expect if, as predicted, using probabilistic precues eliminated task switching and all participants were engaged solely in the color-naming task under both the expected easy and hard conditions. Bugg and Smallwood (2016) observed a similar asymmetry in their experiments, such that congruent responding was most affected by the use of 100 %-valid precues, whereas incongruent responding was primarily affected when they switched to probabilistic (75 %-valid) cues. They also argued that this was due to the 100 %-valid cues enabling a strategic task switch to word reading, whereas probabilistic cues likely involved modulating attention to the word dimension within the color-naming task alone.

The significant reduction in Stroop effects following a HARD precue suggests that participants use precues to modulate attention even when the precues are (1) only 69 % valid, (2) actually nondiagnostic for the critical stimuli, and (3) equally frequent/informative within the experiment. This suggests a general preparatory effect of the precues, in which precue effects generalize beyond items for which the cue validity itself is established, providing strong evidence that the modulation of performance is not due simply to a compound cue–stimulus–response learning mechanism. This is similar to Crump and Milliken's (2009) demonstration that context-specific PC effects can "transfer" to new frequency-unbiased items, refuting compound-learning (context + stimulus + response) explanations of performance (see Crump & Milliken, 2009, for more discussion). Finally, the Precue × Stroop interaction occurred even when both precues were equally informative. This is in contrast to Goldfarb and Henik (2013, Exp. 1), who found no Precue × Trial Type interaction when the overall list PC was 50 %. However, they used only incongruent and neutral trials in their experiment, and as a result, it is likely their participants directed attention away from the word dimension on every trial, because attending to the word would not benefit performance in either condition.

The second critical finding in Experiments 2a and 2b was that we replicated our Experiment 1 finding that precues reduced the ISPC effect. When participants prepared for conflict following a HARD precue, they were less sensitive to item PC information carried by the distractor words. Because this occurred for items for which the precue was nondiagnostic, this demonstrates that participants were not simply using the precues to block specific responses (e.g., to the filler items WHITE or GREEN), but to block word-reading processes in general. This is consistent with our predictions that HARD precues enhance participants' preparation for suppressing distractor words and that such early selection prevents reactive control cues carried by the distractor words from exerting their influence.

General discussion

The present study demonstrated that ISPC effects are attenuated when congruency precues are used, and it conceptually replicated and extended previous findings showing that Stroop effects are reduced when participants expect incongruence (Bugg & Smallwood, 2016; Goldfarb & Henik, 2013). In terms of ISPC effects, we obtained typical ISPC effects in Experiment 1 under noninformative precue conditions, but these were eliminated following 100 %-valid precues, suggesting that the information carried along the distractor word dimension was ignored due to participants' preparatory strategies based on the precue. The elimination of ISPC effects following informative precues is consistent with our hypothesis that the use of precues reduces the influence of correlations between words and PC levels (Jacoby et al., 2003; Melara & Algom, 2003). In other words, item-specific tendencies to capture or deflect attention based on congruency history have minimal effects on performance if selective attention toward word reading or color naming has already been accomplished through preparatory precues. In Experiment 2, as predicted, a similar pattern was observed. ISPC effects were robust following an EASY precue, but they were attenuated and nonsignificant following a HARD precue. This provides additional evidence for the interactivity of proactive and reactive control, such that, under conditions in which precues direct participants to prepare for conflict (i.e., the HARD cue), there is a reduced influence of reactive mechanisms such as item-specific control of word reading (Bugg et al., 2011) or prediction of correlated responses (Melara & Algom, 2003; Schmidt & Besner, 2008; Schmidt et al., 2007).

In addition to the interactivity of precuing and ISPC effects, Experiment 1 revealed interactivity among precuing and list-based PC effects, such that the list-based PC effect found in the noninformative precue conditions was eliminated when precues were given. This suggests that precues may undermine the overall relaxing of control that accompanies experience within an MC list (Kane & Engle, 2003) and the overall stringent control that typically accompanies experience within an MI list (De Pisapia & Braver, 2006). Consistent with this interpretation, the CONFLICTING precue reduced incongruent RTs more when it was embedded within the MC list, and the MATCHING precue reduced congruent RTs more when it was embedded within the MI list (see Fig. 1). Thus, we believe that congruency precues prevent experience with MC or MI items within a list from influencing the engagement (or not) of proactive control.

Whereas the present study suggests that ISPC effects are attenuated when participants' attention is already focused on word reading or color naming, a recent study by Atalay and Misirlisoy (2014) has shown that ISPC effects are also reduced when the onset of distractor words is delayed, relative to the onset of color patches. In this study, participants named colored rectangles that contained embedded congruent or incongruent color words. The words appeared slightly before (−200 ms, −100 ms), simultaneously with (0 ms), or slightly after (+100 ms, +200 ms) the onset of the color (see Glaser & Glaser, 1982). Although the ISPC effects were comparable across word-color stimulus onset asynchronies from −200 to +100 ms, they were eliminated at the +200-ms stimulus onset asynchrony. Thus, consistent with Algom and colleagues' arguments concerning differential salience of the word and color dimensions (see Melara & Algom, 2003, for a review), if distractor words are presented after sufficient color processing has already begun, the informational value of the words no longer influences performance. These results converge with those of the present study in suggesting that ISPC effects can be reduced or eliminated by directing attention to appropriate pathways, either through congruency precues or by delaying the onset of irrelevant information.

In terms of precue effects more generally, Experiment 2 demonstrated that Stroop effects were reduced when participants were (probabilistically) precued to expect incongruence rather than congruence, and that the reduction in the Stroop effect was due to a benefit on incongruent trials following the HARD precue. This finding converges with the ISPC patterns above in suggesting that participants used the HARD precue to engage proactive control to selectively attend to color and to block word reading. At first glance, the pattern of Stroop effects in Experiment 1 may seem inconsistent with this finding. However, Stroop effects could not be calculated separately for each type of congruency precue (MATCHING vs. CONFLICTING) in Experiment 1, due to the use of 100 %-valid precues. The larger Stroop effect in the informative precue condition (than in the noninformative precue condition) therefore reflects the fact that congruent-trial RTs changed more dramatically across precue conditions than did incongruent RTs. In particular, congruent-trial RTs were especially fast in the informative precue condition (i.e., following a MATCHING precue), likely because participants switched to word reading (cf. Bugg & Smallwood, 2016). Reducing the precue validity to 69 % in Experiment 2 was intended to prevent intentional switches to word reading, because this strategy would lead to 31 % errors on incongruent trials. (Note that there was no effect of precues on the error rates in Experiment 2, and overall errors were very low.) Consistent with this goal, inspection of Fig. 3 demonstrates that congruent RTs remained relatively constant across precue conditions, whereas incongruent RTs did not (which we attributed to proactive control, as we discussed above).

Additional advantages of precue manipulations

Olsen, Powell, and Hutchison (under review) recently reviewed the additional benefits of using congruency precues, as opposed to list-based PC manipulations, as a demonstration of proactive control. The problems of manipulating list-based PC include not only the typical list PC and ISPC confound discussed in the introduction, but also potential problems due to sequential effects and different baseline RTs across lists. For instance, list-based PC is naturally confounded with the PC of the immediately preceding trial, meaning that what appears to be sustained proactive control over trials might instead reflect transient micro-adjustments of control based on the immediately preceding trial (Botvinick, Braver, Barch, Carter, & Cohen, 2001; Gratton et al., 1992; but see Verguts & Notebaert, 2008, for an alternative account of conflict adaptation based on enhanced binding between stimuli and tasks following conflict). In addition, the fact that participants are generally faster on MC lists could present a problem. Specifically, Kinoshita and colleagues (Kinoshita & Mozer, 2006; Kinoshita, Forster, & Mozer, 2008; Kinoshita, Mozer, & Forster, 2011) have argued that participants set a time criterion for responding based on a trade-off between speed and accuracy (see Mozer, Colagrosso, & Huber, 2002, for the formal decision model). As a result, one's RT threshold becomes tuned with the average RT within a block, with longer average RTs for blocks containing mostly difficult (e.g., incongruent) items. Kinoshita and colleagues further proposed an asymmetry in which the effect of proportion difficult is greater on easy-item RTs than on hard-item RTs, producing reductions in hard-minus-easy effect sizes in the mostly difficult list. Recently, Schmidt (2013a, b, c; 2014) invoked similar reasoning to explain list-based PC effects in the Stroop task. According to his temporal-learning account, participants develop rhythms of responding based on the overall list context that produce differences in the Stroop effect across lists.

With all of these potential alternative explanations, it has become increasingly difficult to demonstrate proactive control in conflict tasks. Indeed, in many cases, behaviors ascribed to proactive control might instead be caused by participants capitalizing on lower-level associative information, temporal cues, or conflict adaptation. As was argued by Olsen, Powell, and Hutchison (under review), congruency precues eliminate these problems, because the precues are randomized. Thus, when cues are randomized, an EASY (or MATCHING) cue is just as likely to follow a previous congruent trial (or fast-RT trial) as a previous incongruent trial (or slow-RT trial). Moreover, congruency precues allow for an effect of expected congruency, even when both the overall list PC and item-specific PCs are held constant.

Potential limitations

Although we have interpreted the precue effects in this study as reflecting strengthening or relaxing proactive control over word reading on the basis of precues, alternative interpretations are still possible. For instance, it is possible that participants could have used the precues CONFLICTING (Exp. 1) or HARD (Exp. 2) to either avert their gaze or squint their eyes. Either of these strategies should reduce word-reading interference on incongruent trials, but at the expense of word-reading facilitation on congruent trials. However, gaze aversion/squinting accounts would have difficulty explaining the pattern of precueing effects obtained across studies (see Bugg & Smallwood, 2016, for a more detailed discussion). For instance, Goldfarb and Henik (2013) found precueing benefits only within 50 %-incongruent/50 %-congruent lists, but not within 50 %-incongruent/50 %-neutral lists, even though gaze aversion/squinting would have been at least as effective in the latter list. Similarly, Bugg and Smallwood found precue benefits only on incongruent trials at their 2,000-ms conditions, even though participants presumably could have engaged in such activities much more quickly. Finally, we have replicated our precuing effect using an Eriksen (Eriksen & Eriksen, 1974) flanker task (Olsen, Powell, and Hutchison, under review), in which the cues EASY and HARD indicated, with 70 % validity, whether the upcoming items was likely to be congruent (e.g., AAA) or incongruent (e.g., CAC). Such strategies would be counterproductive in an Eriksen flanker task, because the goal to narrowly focus attention (and gaze) solely on the central letter becomes even more important when conflict is expected.

Another alternative account is that our precueing effect was implicit and unintentional. For instance, precues could serve as an implicit external context that automatically modulates word reading (Bugg et al., 2008; Crump, Gong, & Milliken, 2006; Crump & Milliken, 2009). For instance, Crump and colleagues have found that contextual cues such as stimulus location that predict the probability of conflict can automatically modulate the Stroop effect. Unlike in these studies, however, the contextual cue in our study was temporally removed from the stimulus, so it is unclear whether such an automatic, context-specific control effect could occur. In fact, Bugg and Smallwood's (2016) precuing effects actually increased as the temporal separation between the precue and Stroop stimuli increased, and the effects were not significant at the shortest (500-ms) interval. Moreover, Olsen, Powell, and Hutchison (under review) addressed this possibility through a control experiment in which the precues EASY and HARD were replaced with nonwords (i.e., HAUN and BRAB). Unlike with the word precues, the Stroop effects were identical following the nonword precues, regardless of whether they usually preceded congruent or incongruent stimuli. Thus, modulations of Stroop effects based on precues do not appear to be due to implicit context-specific modulation of word reading. Similarly, this control experiment renders unlikely a temporal-learning (Schmidt, 2013b, 2014) explanation that our precuing effects might have been due to the precues serving as implicitly learned proxies for whether the upcoming stimulus should be responded to quickly or slowly.

Finally, a potential concern for Experiment 2 is that the point values were confounded with congruency precues. Our reason for doing this, as we mentioned in the Method section, was that some participants in a previous study (Olsen, Powell, and Hutchison, under review) self-reported ignoring the precues during our debriefing. Because we were primarily concerned with whether participants could use the HARD precue to enhance proactive control, we reasoned that adding the point value would increase participants' motivation to suppress word reading. In doing so, however, we could not differentiate with certainty the effect of knowledge concerning the upcoming congruency from motivation to perform well. We do not consider this a major problem, however, because we were primarily interested in whether participants could use the HARD cues to exert more top-down effort toward color naming, and it was not important whether this increased effort was due to knowledge regarding the upcoming difficulty or the possibility of upcoming reward. Nonetheless, future studies could orthogonally manipulate point values and congruency precues to disentangle the effects of congruency expectations from the effects of overall motivation. We should note, however, that Olsen et al. (in their Exp. 1) used the same procedure as in our present Experiment 2, but without the point values (and using only PC50 items), and obtained a Precue × Stroop Effect interaction at least as large (η_p^2 = .180) as that found in the present Experiment 2 (η_p^2 = .096). Thus, it is more likely that our precueing effects were due solely to the precues themselves, and not to the point values.

Conclusion

The goal of the present study was to examine whether ISPC effects are mutable, via a manipulation designed to influence proactive control. In both experiments, we found that ISPC effects could indeed be reduced either when participants knew with certainty to which pathway to direct attention (Exp. 1) or under conditions in which they expected conflict, and thus engaged in early selection of color information (Exp. 2). In addition, in Experiment 1 the use of precues eliminated the typical list-based PC effect. These data thus extend prior precueing studies by suggesting interactivity between top-down, proactive processing and bottom-up, reactive processing.

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