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The relative attractiveness of distractors and targets affects the coming and going of item-specific control: Evidence from flanker tasks

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Abstract The item-specific proportion congruence (ISPC) effect refers to the attenuation of interference for mostly incongruent relative to mostly congruent items. In the present study, qualitatively different ISPC effects were observed in letter- and arrow-based flanker tasks despite their common use of the original two-item set design. Consistent with the predictions of the dual item-specific mechanisms account, contingency-driven ISPC effects were observed when stimuli were used that attracted attention to the irrelevant dimension (Experiments 1, 3, and 6), whereas control-driven ISPC effects were observed when attention was attracted to the relevant dimension (Experiments 2, 4, and 5). The evidence for control-driven ISPC effects in the two-item set design (1) challenges the contingency account, which claims that ISPC effects are solely contingency-driven, and (2) supports an expanded definition of cognitive control that includes fast and flexible adjustments that minimize attention to distractors upon encountering stimuli that have previously been associated with a history of conflict.

Keywords Cognitive and attentional control · Cognitive control and automaticity · Flanker task

A central theoretical issue in the cognitive control literature concerns the mechanisms that modulate interference in conflict tasks such as Stroop and flanker. About a decade ago, Jacoby, Lindsay, and Hessels (2003) demonstrated that the magnitude of Stroop interference, the slowed naming of the color on incongruent (i.e., YELLOW in blue ink) relative to congruent (i.e., BLUE in blue ink), trials varied dramatically depending on a particular word's history of conflict. Interference was attenuated for words that were frequently presented in an incongruent format (i.e., mostly incongruent [MI] items), relative to words that were frequently presented in a congruent format (i.e., mostly congruent [MC] items).[1] They termed this pattern the item-specific proportion congruence (ISPC) effect. What was intriguing about the ISPC effect was the "automatic control" mechanism posited to produce it (Jacoby et al., 2003, p. 643). This mechanism, unlike the global and strategic mechanism suggested to underlie list-wide proportion congruence effects (i.e., less interference for MI lists relative to MC lists; Logan & Zbrodoff, 1979; Lowe & Mitterer, 1982), involved a rapidly acting and flexible form of control that modulated attention to the irrelevant dimension post-stimulus-onset, following retrieval of the appropriate (item-specific) control settings. For example, MI items presumably triggered retrieval of a control setting that rapidly attenuated processing of the irrelevant dimension—that is, a setting that coincided with the item's history of conflict (see Shedden, Milliken, Watter, & Monteiro, 2013, for ERP evidence that MC and MI items are distinguished as early as 150 ms post-stimulus-onset in the Stroop task). The upshot is that researching the ISPC effect affords the opportunity to enhance our understanding of stimulus-driven (item-specific) control of interference (for reviews, see Bugg, 2012; Bugg & Crump, 2012; for evidence of context-specific proportion congruence effects that similarly afford such an opportunity, see also Crump & Milliken, 2009; King, Korb, & Egner, 2012).

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[1] Frequency accounts (e.g., Logan, 1988) have therefore been evaluated as explanations of the ISPC effect. A major piece of evidence arguing against such accounts is the results of the process-dissociation procedure showing that ISPC selectively influences the word-reading process (Jacoby et al., 2003). If frequency was driving the effect, this procedure should have revealed an influence on both the color and word processes, since it is particular combinations that are more or less frequent.

An important message that has emerged from ISPC experiments, however, is that not all ISPC effects necessarily yield knowledge regarding stimulus-driven control. One view, the contingency account (Schmidt & Besner, 2008), posits that ISPC effects are entirely attributable to simple stimulus–response associations and have nothing to do with an item's history of conflict (i.e., ISPC) (see Schmidt, 2013a, for a similar view based on retrieval of prior learning episodes). Participants learn correlations between distractors (e.g., words) and responses (e.g., colors), and these correlations permit prediction of a high-contingency response on select trials, producing the ISPC pattern. As is shown in Fig. 1, in the original two-item set ISPC design in which unique words and colors formed the MC and MI sets (Jacoby et al., 2003), there were two such high-contingency trial types: MC-congruent trials and MI-incongruent trials. As predicted by the contingency account, the resultant ISPC pattern was symmetrical, reflecting a speeding of response times (RTs) on these high-contingency trial types (see Fig. 2a. for an illustration of this pattern).

An alternative view, the dual item-specific mechanisms (dual-ISM) account,[2] posits that item-specific contingency learning is only one possible mechanism that may contribute to ISPC effects (Bugg & Hutchison, 2013; Bugg, Jacoby, & Chanani, 2011). Item-specific control is the second mechanism. In this case, participants learn correlations between a dimension (e.g., the color green) and ISPC (e.g., MI). Upon stimulus onset (e.g., WHITE in green ink), the "MI" attentional setting (i.e., rapidly attenuate processing of the word) is retrieved. As such, the type of association underlying item-specific control has been described as a *stimulus–attention* association (Bugg & Crump, 2012; Crump & Milliken, 2009), which contrasts with the *stimulus–response* association underlying contingency learning.

The dual-ISM account uniquely predicts that the dominance of one versus the other item-specific mechanism in producing ISPC effects depends on the relative attractiveness of the target (the relevant dimension) and distractors (the irrelevant dimension). To the extent that one dimension attracts more attention, the cognitive system will capitalize on the information that is correlated with that dimension (Bugg et al., 2011a). The roots of the dual-ISM account can be traced to tectonic theory (Melara & Algom, 2003), which characterized the influential effects of "distractor information" on failures of target selection in the Stroop task. According to tectonic theory, correlated information and surprising information contribute to a structure called *dimensional uncertainty*. The idea is that a distractor (the irrelevant dimension) will attract more attention (making selection failures more probable) to the extent that distractor values are correlated with target values or are more uncertain (i.e., more surprising to the observer) (cf. Dishon-Berkovits & Algom, 2000). Salient information also plays a role by contributing to a structure called *dimensional imbalance*, which is defined as the relative accessibility of the relevant and irrelevant dimensions. When the psychophysical context favors discrimination of distractor values (e.g., when distractors are more salient due to physical differences between stimuli), attention is attracted to the irrelevant dimension, and activation of the target is impeded.

The idea that attractive distractors command attention and impede target selection is central to understanding the dual-ISM account's position that ISPC effects, at times, reflect a contingency learning mechanism and, at other times, reflect an item-specific control mechanism. The former mechanism depends on attention being drawn to the irrelevant dimension (i.e., attractive distractors), while the latter depends on attention to the relevant dimension. In prior color–word Stroop ISPC studies (e.g., Jacoby et al., 2003; & Besner, 2008), dimensional imbalance favored discrimination of and access to the irrelevant word (Fraisse, 1969; Melara & Algom, 2003; Melara & Mounts, 1993; Virzi & Egeth, 1985). Accordingly, and in line with the dual-ISM account, use of the two-item set design produced a contingency-driven ISPC effect that reflected use of information that was correlated with the irrelevant dimension (i.e., correlations between the words and colors to predict high contingency responses on MC-congruent and MI-incongruent trials), as depicted in Table 1.[3] When dimensional imbalance favors the relevant dimension (target), however, the dual-ISM account predicts that ISPC effects will be driven by the one type of information that is correlated with that dimension (i.e., ISPC; see Table 1) and, therefore, reflect item-specific control. Only the dual-ISM account makes this prediction; the contingency account predicts that ISPC effects are always contingency-driven.

In an initial test of the dual-ISM account, Bugg et al. (2011a) used a variant of the two-item set design and manipulated the attractiveness of the irrelevant and relevant dimensions in a picture–word Stroop task. When only the irrelevant

[2] In prior studies (Bugg & Hutchison, 2013; Bugg et al., 2011a), the dual-ISM account was termed the "item-specific control account." The new label was adopted to better capture the account's position that item-specific control *and* contingency learning produce ISPC effects, albeit under different conditions, and to minimize potential confusion between the terms "item-specific control account" and "item-specific control."

[3] It is possible that the symmetrical pattern suggested to characterize contingency learning in the study of Jacoby et al. (2003; see Schmidt & Besner, 2008) resulted from the operation of a contingency-learning mechanism on MC-congruent trials and an item-specific control mechanism on MI-incongruent trials. If so, the ISPC pattern that characterizes contingency learning may be an asymmetrical one in which ISPC selectively speeds MC-congruent, relative to MI-congruent, trials, including in the original two-item set design (see Bugg et al., 2011a, Experiment 3, for evidence of this pattern in a variant of the two-item sets design in which words from one set appeared with pictures from that set *and* the opposite set such that only MC-congruent trials were of the high contingency type).

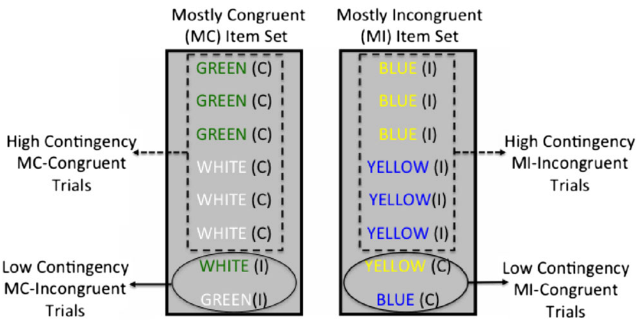

Fig. 1 Illustration of stimuli and trial types in the original two item-set item-specific proportion congruence design (Jacoby et al., 2003) in which unique targets (colors) and distractors (words) make up each set. High-contingency trials represent the most frequently occurring trial type within each set (e.g., MC-congruent and MI-incongruent), while low-contingency trials are the less frequently occurring trial type within each set (e.g., MC-incongruent and MI-congruent)

dimension was informative (i.e., was reliably correlated with ISPC and, accordingly, contingent responses) and thereby attracted attention (Melara & Algom, 2003), the resultant ISPC pattern was consistent with a contingency learning mechanism. A selective speeding of RTs was observed on the high-contingency MC-congruent items, relative to the MI-congruent items (see Fig. 2b for an illustration of this ISPC pattern; Bugg et al., 2011a, Experiment 3). In stark contrast, when only the relevant dimension was informative (i.e., was reliably correlated with ISPC), thereby attracting attention, the ISPC effect was characterized by a selective, speeding of RTs on MI-incongruent relative to MC-incongruent trials (see Fig. 2c. for an illustration of this ISPC pattern; Bugg et al., 2011a, Experiment 2; for a replication and extension with the color–word Stroop task, see Bugg & Hutchison, 2013). This pattern aligns with the operation of the item-specific control mechanism described in two extant computational models (Blais, Robidoux, Risko, & Besner, 2007; Verguts & Notebaert, 2008). Both models posit that item-specific control is triggered by conflict, which is present on incongruent trials but not on congruent trials (which explains why there was no RT difference between MI-congruent and MC-congruent trials). The models also posit that the greater the history of conflict for a given item, the stronger the control signal (i.e., to enhance processing of the relevant dimension [Blais et al., 2007] or additionally attenuate processing of the irrelevant dimension [Verguts & Notebaert, 2008]). This is consistent with the faster responding observed on MI-incongruent relative to MC-incongruent, trials.

Distractor and target attractiveness in the two-item set design

Because the irrelevant and relevant dimensions are both reliably correlated with ISPC in the original two-item set design (see Table 1), testing the dual-ISM account via this design requires use of an alternative experimental approach. Here, the approach that was used was to alter the relative attractiveness of the two dimensions by manipulating their salience (i.e., shifting dimensional imbalance). Examining the contributions of item-specific contingency learning and item-specific

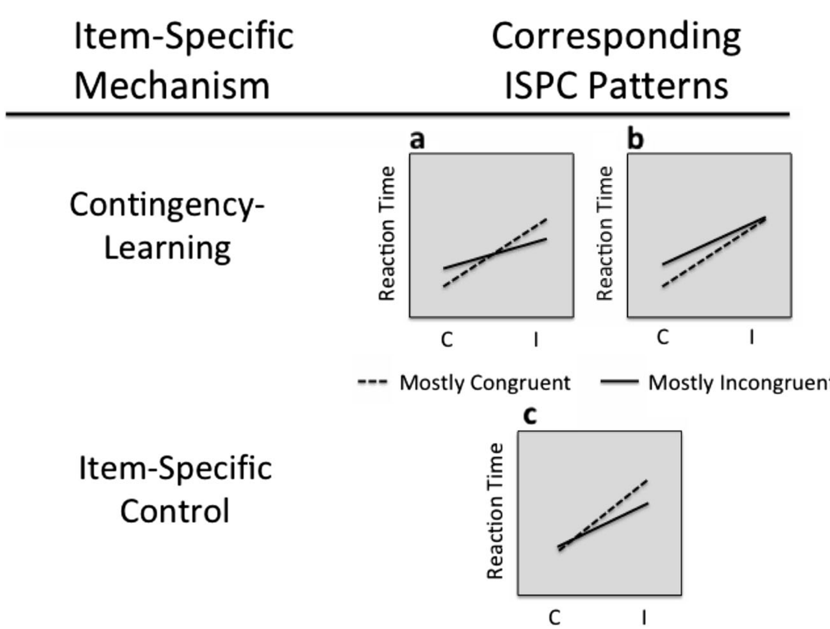

Fig. 2 Item-specific proportion congruence (ISPC) patterns that correspond to the operation of a contingency learning mechanism (**a**, **b**) or to the operation of an item-specific control mechanism (**c**). Panel a represents a symmetrical pattern whereby reaction time is speeded for high-contingency trials of the congruent and incongruent type. Panel b represents a selective influence of ISPC on congruent trials. Panel c represents a selective influence of ISPC on incongruent trials. C = congruent; I = incongruent

Table 1 Type of information that is correlated with the irrelevant (distractor) and relevant (target) dimensions in the original two-item set item-specific proportion congruence design implemented in Experiments 1 through 5

Dimension	Type of Information	Correlated Information?	Item-Specific Proportion Congruence & Trial Type			
			Mostly Congruent		Mostly Incongruent	
			Congruent	Incongruent	Congruent	Incongruent
Irrelevant	ISPC	yes	.75	.25	.25	.75
	Response contingency	yes	high (.75)	low (.25)	low (.25)	high (.75)
Relevant	ISPC	yes	.75	.25	.25	.75
	Response contingency	no	high (1.0)	high (1.0)	high (1.0)	high (1.0)

control via the two-item set design is of theoretical value because the two mechanisms are on equal footing, so to speak, such that either mechanism could produce an ISPC effect. In other words, this design does not minimize the effectiveness or preclude use of contingency learning (e.g., by eliminating high-contingency MI-incongruent trials), which is a potential criticism of some designs that have challenged the contingency account by providing evidence for item-specific control (e.g., Bugg et al., 2011a; Bugg & Hutchison, 2013; see Schmidt, 2014). Rather, the irrelevant dimension is informative of a high-contingency response for both MC and MI items in this design.

To date, it has yet to be shown that one can alter the strong dimensional imbalance that favors attention to the irrelevant dimension in color–word Stroop, which produces contingency-driven ISPC effects (Jacoby et al., 2003; Schmidt & Besner, 2008; see also Atalay & Misirlisoy, 2012; Bugg & Hutchison, 2013). In the picture–word Stroop task, however, there is evidence for a control-driven ISPC effect with use of the two-item set design (Bugg et al., 2011a, Experiment 1). To shift dimensional imbalance in favor of the relevant dimension, Bugg et al. (2011a) modified the psychophysical context (e.g., pictures were larger than words; detailed pictures were used to reduce the pop-out of words). Also, to increase the surprisingness of the relevant dimension, which attracts attention, a larger set of pictures than words was used (Melara & Algom, 2003). The resultant ISPC effect reflected a speeding of RTs on MI-incongruent trials relative to MC-incongruent trials, the pattern that accompanies conflict-triggered item-specific control (see Fig. 2c.; cf. Blais et al., 2007; Verguts & Notebaert, 2008).

Present study

The aim of the present study was to further contrast theoretical accounts of the ISPC effect, utilizing solely the original two-item set design. The flanker paradigm (e.g., Eriksen & Eriksen, 1974) was chosen as the conflict task. Although there are notable differences between Stroop and flanker that could hypothetically limit applicability of ISPC theories from the Stroop literature to flanker tasks, such as the use of spatial attention in flanker but not in classic versions of Stroop (see Chajut, Schupak, & Algom, 2009), the flanker paradigm seemed particularly advantageous for the present goal. Unlike Stroop tasks, the interference that arises in flanker paradigms does not reflect the need to override a habitual tendency to process the irrelevant dimension on the basis of years of experience (i.e., with reading). In other words, there is not necessarily a strong dimensional imbalance favoring the irrelevant dimension (Fraisse, 1969; Melara & Algom, 2003) in the flanker paradigm. Therefore, the flanker paradigm seemed well suited to (1) examine the dual-ISM account's predictions that a contingency-driven ISPC effect would result when attention was biased toward (attracted to) the irrelevant dimension, whereas a control-driven ISPC effect would result when attention was biased toward (attracted to) the relevant dimension, and (2) contrast these predictions with those of the contingency account, which expects ISPC effects always to be contingency-driven in the two-item set design.

To my knowledge, there has been only one prior study that manipulated ISPC in a flanker paradigm (but see, e.g., Bugg, 2014a; Corballis & Gratton, 2003; Crump, Gong, & Milliken, 2006; Crump & Milliken, 2009; King et al., 2012; Lehle & Hübner, 2008; Vietze & Wendt, 2009; Wendt, Kluwe, & Vietze, 2008, for evidence of stimulus-driven control in flanker paradigms in which context-specific proportion congruence was manipulated). Wendt and Luna-Rodriguez (2009, Experiment 3) randomly assigned target and distractor values on each trial for one group of participants. For the other, critical group, two distractor values (e.g., K and L) occurred more frequently on congruent trials, while the two other distractor values (N and P) occurred more frequently on incongruent trials. Unlike the original two-item set design, all distractor values appeared with all four targets, such that there was no high-contingency MI-incongruent trial type. For the critical group only, it was found that flanker interference was reduced for flankers that were associated with a frequent, as opposed to infrequent, history of conflict. This stemmed from a speeding of responses on congruent trials for MC (K and L) flankers and incongruent trials for MI (N and P) flankers. The authors concluded that both an attentional refocusing mechanism postflanker identification (cf. item-specific control) and correlational distractor–response priming (cf. item-specific contingency learning) were at play.

The present study extends the work of Wendt and Luna-Rodriguez (2009) by manipulating ISPC using the original two-item set design in letter-based and arrow-based flanker paradigms. As is illustrated in Table 1, targets and distractors are both correlated with ISPC in this design, and as such, tectonic theory would suggest that both dimensions are carrying correlated information in the letter- and arrow-based paradigms.[4] Across the two flanker paradigms, the dimensions were also equated on surprisingness (dimensional uncertainty) by ensuring that targets (here, the central stimulus) and distractors (here, the flankers) were equally uncertain (i.e., presented equally often relative to other possible targets or distractors). However, differences between the letter and arrow stimuli were anticipated to produce variation in salience (i.e., ease with which targets and distractors are activated, reflecting their discriminability) and, therefore, influence dimensional imbalance. It was assumed that the distinctive perceptual features (orthography) that characterized the letters would facilitate discriminability of the six flanking distractors, while the nondistinctive perceptual features (similarly angled lines) characterizing the arrows would minimize distractor salience (see Fig. 3). As a consequence, it was expected that distractor letters would be difficult to ignore (i.e., would be more likely to attract attention), whereas distractor arrows would not be readily attended (i.e., attention would favor the relevant dimension).

Experiment 1

The letter-based flanker paradigm was employed in Experiment 1. The dual-ISM account predicted that dimensional imbalance would favor attending to the irrelevant dimension due to its salience (i.e., ease of discriminating flankers from the target), and the cognitive system would capitalize on the information carried by this dimension, resulting in a contingency-driven ISPC effect (see Fig. 2a, b, for corresponding ISPC patterns). This prediction coincides with that of the contingency account, which claims that ISPC effects are always contingency driven (Schmidt & Besner, 2008). Alternatively,

[4] The tectonic theory of Melara and Algom (2003) was formulated in the context of Stroop tasks where dimensions referred to the relevant (color) and irrelevant (word) information. I am generalizing the theoretical assumptions to the flanker task, where the relevant dimension is the central target and the irrelevant dimension refers to the peripheral flankers.

Experiment	Flanker Stimuli		Attractive (Salient) Distractors?
1	KKKHKKK	SSSCSSS	yes
2	<<<><<<	∧∧∧∨∧∧∧	no
3	LLLRLLL	UUUDUUU	yes
4	<<<><<<	∧∧∧∨∧∧∧	no
5	NNNZNNN	YYYXYYY	no
6	<<<><<<	∧∧∧∨∧∧∧	yes*

Fig. 3 Sample flanker stimuli (incongruent only) from the letter- and arrow-based paradigms in Experiments 1 through 6. The rightmost column indicates whether the distractors (irrelevant dimension) were predicted to attract more attention based on their salience. * = attractiveness determined in part on basis of correlated information carried by the distractors in Experiment 6 but not Experiment 2

it was possible that contrary to both accounts, the ISPC pattern would be control-driven (see Fig. 2c).

Method

Participants

The participants were 23 Washington University undergraduates who participated for course credit. All participants had normal or corrected-to-normal vision and were right-handed.

Design and materials

A 2 (ISPC: MC vs. MI) × 2 (trial type: congruent vs. incongruent) within-subjects design was implemented within a letter-based flanker paradigm. As is shown in Table 2, for

Table 2 Frequency of trial types in two-item set design of Experiments 1, 3, and 5

ISPC	Flankers	Target K	Target H	Target S	Target C
MC	K	72	24	0	0
	H	24	72	0	0
MI	S	0	0	24	72
	C	0	0	72	24

Note. Assignment of letter sets to mostly congruent (MC) or mostly incongruent (MI) conditions was counterbalanced across participants. The letters K, H and S, C were used as letter sets in Experiment 1, as depicted in the table, whereas the letters L, R, and U, D, respectively, were used in Experiment 3 and N, Z, and Y, X, respectively, were used in Experiment 5 the MC set, 75% of trials were congruent and 25% incongruent. For the MI set, 25% of trials were congruent and 75% were incongruent. Combining the two sets yielded lists of trials that were 50% congruent. The letters "S" and "C" were assigned to one set, and "H" and "K" were assigned to a second set (for sample stimuli, see Fig. 3), with assignment of letter pairs to ISPC levels counterbalanced across participants. As in prior ISPC studies employing the original two-item set design (e.g., Jacoby et al., 2003), items were not permitted to cross sets (i.e., a C target never appeared with H flankers).

Procedure

Participants were initially instructed on and given practice with the stimulus–response mappings. Instructions emphasized accurately learning the mappings (i.e., on the number pad, 8 = S; 6 = H; 2 = C; 4 = K) not speed. A single letter was shown on screen until a response was made, followed by corrective feedback (e.g., "Correct" or "Incorrect—the correct response was . . .") for 2,000 ms. Twenty-four practice trials were provided (6 of each letter). Participants were then instructed on the flanker task. They were told to respond to the central letter and ignore flanking letters, of which there were three on each side (e.g., SSSCSSS). The right index finger was used to respond, and the finger was rested on the "5" key between trials. Following eight practice trials, there were four blocks of 96 trials, with brief breaks between blocks. Within each block, 50% of trials were congruent and 50% were incongruent (due to the random intermixing of the MC and MI items). Stimuli were centrally presented until a response was made. A fixation point appeared below the central stimulus and remained on screen during the otherwise blank 1,000-ms response-to-stimulus interval. RTs (in milliseconds) and accuracy were recorded.

Results

Trials for which responses were <200 ms or >2,000 ms were removed, eliminating <1% of trials. Additionally, incorrect trials were eliminated for the analysis of RT. For this and subsequent experiments, the alpha level was set at .05, and other than those reported, no other effects were significant.

A 2 (ISPC) × 2 (trial type) within-subjects ANOVA was conducted for RT. The main effects of ISPC, $F(1, 22) = 11.06$, $MSE = 2{,}211.15$, $p = .003$, $\eta_p^2 = .334$, and trial type, $F(1, 22) = 15.56$, $MSE = 1{,}875.36$, $p = .001$, $\eta_p^2 = .414$, were significant. They were qualified by a significant ISPC × trial type interaction, indicating an ISPC effect, $F(1, 22) = 14.04$, $MSE = 674.40$, $p = .001$, $\eta_p^2 = .390$. Flanker interference (i.e., the magnitude of RT slowing on incongruent, as compared with congruent, trials) was significantly less robust for the MI set of items ($M = 15$), as compared with the MC set of items ($M = 56$) (see Fig. 4). Planned comparisons indicated that a significant RT advantage ($M = 53$) was found on the congruent trials for MC items relative to MI items, $F(1, 22) = 47.71$, $p < .001$. There was no difference as a function of ISPC for the incongruent trials, $F(1, 22) = 2.59$, $p > .05$. For the analysis of error rate, an identical ANOVA revealed no significant effects. The error rate was ~.04 for all combinations of ISPC and trial type (see Table 3).

Discussion

Experiment 1 employed the original two-item set design (Jacoby et al., 2003) in a letter-based flanker paradigm. An ISPC effect was found due to significantly less interference for MI items than for MC items (see also Wendt & Luna-Rodriguez, 2009). The ISPC pattern was characterized by an RT advantage for MC-congruent trials (relative to MI-congruent trials), but no difference in RTs for incongruent trials. This pattern is of theoretical importance because it speaks to possible underlying mechanisms. The pattern indicates that item-specific control was not responsible for the effect, because a signature of item-specific control is the selectively or disproportionately pronounced influence of ISPC on incongruent trials (see Fig. 2c; Bugg & Hutchison, 2013; Bugg et al., 2011a; cf. Schmidt & Besner, 2008, for the similar view that the modulation of word reading via control should have a stronger effect on incongruent trials and little to no effect on congruent trials). The pattern is consistent with the operation of a contingency learning mechanism. Although the contingency account anticipated the symmetrical ISPC pattern shown in Fig. 2a (Schmidt & Besner, 2008), a selective speeding of RTs on MC-congruent trials

Fig. 4 Mean reaction time (in milliseconds) as a function of trial type for MC and MI items in the letter-based flanker task with S/C and H/K as letter sets in Experiment 1. Error bars represent standard errors of the means

Table 3 Mean error rates (with standard errors) as a function of item-specific proportion congruence and trial type in Experiments 1 through 6

		Mostly Congruent Items		Mostly Incongruent Items	
		Congruent	Incongruent	Congruent	Incongruent
Experiment	1	.037 (.005)	.038 (.010)	.033 (.005)	.037 (.005)
	2	.001 (.001)	.049 (.013)	.007 (.005)	.028 (.008)
	3	.017 (.004)	.013 (.004)	.018 (.005)	.019 (.003)
	4	.006 (.001)	.012 (.004)	.005 (.002)	.014 (.003)
	5	.043 (.008)	.048 (.007)	.045 (.008)	.038 (.007)
	6	.011 (.002)	.031 (.009)	.026 (.007)	.024 (.007)

(relative to MI-congruent) has also been found to accompany a contingency-driven ISPC effect (see Fig. 2b.; Bugg et al., 2011a, Experiment 3).

Experiment 2

The original two-item set design was employed in an arrow-based flanker paradigm in Experiment 2. On the basis of tectonic theory (Melara & Algom, 2003), it was assumed that dimensional imbalance would not favor attending to the irrelevant dimension, because of the difficulty in discriminating the distractor (flanking) arrows from the target due to the overlapping perceptual features. Thus, the dual-ISM account predicted that participants would attend to and utilize the information (ISPC) carried by the relevant dimension (target), resulting in a control-driven ISPC effect (Bugg et al., 2011a). This would be evidenced by a selective or disproportionately larger effect of ISPC on incongruent trials (see Fig. 2c.; Bugg & Hutchison, 2013; Bugget al., 2011a). The contingency account, by contrast, predicted that the ISPC effect should again be contingency driven (Schmidt & Besner, 2008).

Method

Participants

Fourteen Washington University undergraduates participated for course credit. All participants had normal or corrected-to-normal vision and were right-handed.

Design and materials

The design (see Table 4) and materials were identical to those in Experiment 1, with the exception that an arrow-based flanker paradigm was used, and “<” and “>” arrows were assigned to one set, whereas “∧” and “∨” arrows were assigned to the other set (for sample stimuli, see Fig. 3).

Table 4 Frequency of trial types in two-item set design of Experiments 2, 4, and 6

		Target			
ISPC	Flankers	<	>	∧	∨
MC	<	72	24	0	0
	>	24	72	0	0
MI	∧	0	0	24	72
	∨	0	0	72	24

Note. Assignment of arrow sets to mostly congruent (MC) or mostly incongruent (MI) conditions was counterbalanced across participants. Note that identical stimuli were used in Experiment 6. In Experiment 4, however, the size of the central target stimulus was disproportionately larger than the size of the flankers

Procedure

The procedure was identical to that in Experiment 1, with the exception that the stimulus–response mapping phase was excluded because the stimuli were naturally mapped to the responses (i.e., on the number pad, 8 = ∧; 6 = >; 2 = ∨; 4 = <).

Results

The trimming procedures were identical to those in Experiment 1, with exclusion of RT outliers resulting in <1% of trials being eliminated.

A 2 (ISPC) × 2 (trial type) within-subjects ANOVA was conducted for RT. The main effect of trial type was significant, $F(1, 13) = 204.27$, $MSE = 1{,}212.05$, $p < .001$, $\eta_p^2 = .940$, and was qualified by a significant ISPC × trial type interaction, $F(1, 13) = 4.90$, $MSE = 1{,}573.40$, $p = .045$, $\eta_p^2 = .274$. Flanker interference was significantly less robust for the MI set of items (M = 110), as compared with the MC set of items (M = 156). Like the ISPC effect in Experiment 1 (see Fig. 1), the interaction pattern was asymmetrical for the arrow-based task in the present experiment (see Fig. 5). However, unlike in Experiment 1, planned comparisons indicated that the asymmetry reflected a significant RT advantage (M = 34) on incongruent trials for MI relative to MC items, $F(1, 13) = 5.29$, $p < .05$. RTs on congruent trials did not vary as a function of ISPC, $F < 1$.

For error rate, the 2 × 2 within-subjects ANOVA revealed a similar pattern of effects. A main effect of trial type, $F(1, 13) = 13.55$, $MSE = .001$, $p = .003$, $\eta_p^2 = .510$, was qualified by an ISPC × trial type interaction, $F(1, 13) = 10.91$, $MSE < .001$, $p = .006$, $\eta_p^2 = .456$. There was less interference in error rate for the MI items, as compared with the MC items (see Table 3 for means).

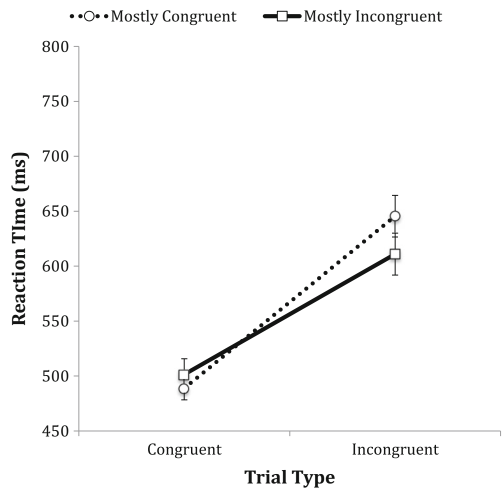

Fig. 5 Mean reaction time (in milliseconds) as a function of trial type for MC and MI items in the traditional arrow-based flanker task in Experiment 2. Error bars represent standard errors of the means

Discussion

Experiment 2 utilized a two-item set design in an arrow-based flanker paradigm, and an ISPC effect was found. However, unlike the ISPC pattern found in Experiment 1, in the present experiment, there was a selective influence of ISPC on incongruent trials and an absence of an effect of ISPC on congruent trials. The ISPC pattern in the present experiment mirrored that which has been observed in prior studies demonstrating control-dominated ISPC effects (Bugg & Hutchison, 2013, Experiments 1, 2, and 3; Bugg et al., 2011a, Experiments 1 and 2) and, therefore, challenges the contingency account (Schmidt & Besner, 2008).[5] Collectively, the findings of Experiments 1 and 2 provide preliminary support for the predictions posited by the dual-ISM account on the basis of tectonic theory (Melara & Algom, 2003).[6] Before considering the theoretical implications more fully, I first report two experiments that aimed to systematically replicate the qualitatively different ISPC patterns observed in the letter-based (Experiment 3) and arrow-based (Experiment 4) flanker paradigms. A potential criticism of the present experiment was the relatively small sample size; thus, in Experiments 3 and 4, sample sizes were at least as large as in Experiment 1.

[5] The overall slowed responding in Experiment 1, relative to Experiment 2, speaks to a recent revision of the contingency account. Schmidt (2013a) noted that Schmidt and Besner (2008) were mistaken in asserting that a contingency mechanism would not produce a stronger effect on incongruent trials. He suggested that contingency effects could actually be larger for incongruent than for congruent trials because incongruent trials take longer to process and, therefore, contingency has more time to affect behavior. Given that it took ~100 ms longer on average to respond to incongruent trials in Experiment 1 than in Experiment 2, on this view, the effect of ISPC on incongruent trials should have been stronger in Experiment 1 than in 2 if a contingency mechanism were operative in both experiments (which was not found).

[6] To evaluate whether stimulus type-specific Gratton effects contributed to the qualitatively different ISPC patterns across Experiments 1 and 2, a four-way analysis was performed with previous PC, previous trial type, current PC, and current trial type as factors. There was no evidence for a stimulus type-specific Gratton effect in either experiment (i.e., no interactions of previous PC or previous trial type with the ISPC effect, nor a four-way interaction, *ps* > .10).

Experiment 3

In Experiment 3, the original two-item set design was used with the MC and MI sets each being composed of two unique letters, as in Experiment 1. However, here the letters corresponded to the first letter of the words left (L), right (R), up (U), and down (D), and participants pressed, for example, the left key when encountering "L" in the central target position. These letters afforded a more natural mapping of stimuli to responses, similar to the arrow-based flanker paradigm. Because the distractor and target letters still consisted of unique perceptual features (i.e., orthography), as in Experiment 1, this change was not expected to affect salience (ease of discriminating flanking letters from the target). Consequently, the dual-ISM account predicted that the cognitive system would (again) capitalize on the information carried by the irrelevant dimension—namely, stimulus–response contingencies—a prediction that converged with the contingency account.

Method

Participants

Twenty-four Washington University undergraduates participated for course credit or monetary compensation. All participants had normal or corrected-to-normal vision and were right-handed.

Design and materials

The design (see Table 2) and materials were identical to those in Experiment 1, with the exception that the letters R and L were assigned to one set, whereas U and D were assigned to the other set (for sample stimuli, see Fig. 3).

Procedure

The procedure was identical to that in Experiment 1, with the exception that the stimulus–response mapping phase was excluded because the stimuli were mapped to the responses (i.e., on the number pad, 8 = U; 6 = R; 2 = D; 4 = L).

Results

The trimming procedures were identical to those in the previous experiments, with exclusion of RT outliers resulting in <1% of trials being eliminated.

For RT, the 2 (ISPC) × 2 (trial type) within-subjects ANOVA yielded a significant main effect of trial type due to flanker interference, $F(1, 23) = 115.01$, $MSE = 310.71$, $p < .001$, $\eta_p^2 = .833$, which was qualified by a significant ISPC × trial type interaction, $F(1, 23) = 14.15$, $MSE = 1{,}103.45$, $p = .001$, $\eta_p^2 = .381$ (see Fig. 6). To examine the locus of the ISPC effect, planned comparisons were conducted. Congruent trials from the MC set were 28 ms faster than those from the MI set, $F(1, 23) = 8.79$, $p < .01$. There was also a statistically significant speeding of 24 ms on incongruent trials from the MI set relative to the MC set, $F(1, 22) = 5.55$, $p < .05$. For error rate, the 2 × 2 ANOVA revealed no significant effects (see Table 3 for means).

Discussion

The primary change from Experiment 1 was the use of letters that corresponded to the first letter of the four possible responses (see Fig. 3). While this change sped RTs, as anticipated, it was not expected to influence the salience of the distractor letters. As predicted by the dual-ISM account, the findings of Experiment 3 converged with those observed in the letter-based paradigm in Experiment 1, with the ISPC pattern being consistent with the operation of a contingency mechanism. One difference between the findings of Experiments 1 and 3 was that the present pattern was symmetrical with the ISPC manipulation speeding RTs on both high-contingency trial types (i.e., MC-congruent and MI-incongruent), as predicted by the contingency account (Schmidt & Besner, 2008). In Experiment 1, the ISPC pattern reflected a selective influence of the ISPC manipulation on the congruent trials, a pattern that has also characterized contingency-driven ISPC effects (Bugg et al., 2011a, Experiment 3). Importantly, in neither experiment was there a selective or disproportionate influence of ISPC on incongruent trials, the pattern that is reflective of item-specific control (see Fig. 2c.). The findings of Experiments 1 and 3 are therefore consistent in showing that ISPC effects in the letter-based flanker paradigm appear to be contingency-driven when the original two-item set design is employed.

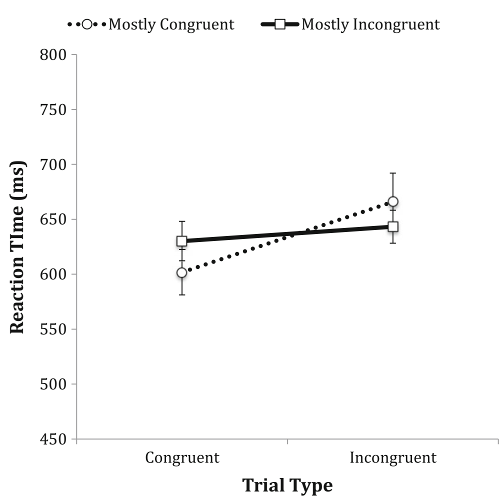

Fig. 6 Mean reaction time (in milliseconds) as a function of trial type for MC and MI items in the letter-based flanker task with U/D and R/L as letter sets in Experiment 3. Error bars represent standard errors of the means

Experiment 4

The purpose of Experiment 4 was to replicate the ISPC pattern observed in Experiment 2 with a theoretically motivated variant of the arrow-based flanker paradigm. Comparison of the magnitude of flanker interference across the preceding experiments showed that interference effects were substantially smaller in the letter-based paradigms (*M*s = 36 and 39 ms, respectively, for Experiments 1 and 3) than in the arrow-based paradigm used in Experiment 1 ($M = 133$ ms). It is possible that evidence for item-specific control was limited to the arrow-based paradigm because there was more interference to be controlled, and not because attention was less attracted to the irrelevant dimension when arrow flanker stimuli were used. To reduce the magnitude of flanker interference in the present experiment, the central target arrow was presented in a larger size than the flanker arrows (see Fig. 3 for sample stimuli), such that it was easier for participants to spatially segregate the target from the flankers (e.g., ignore the flankers). Importantly, although it was expected that use of these stimuli would produce levels of interference that would more closely approximate the levels observed in the letter-based flanker paradigm, a control-driven ISPC effect was still anticipated by the dual-ISM account. This is because the salient relevant dimension (target) was expected to attract attention, thereby permitting the cognitive system to capitalize on the information it conveys (i.e., ISPC; see Table 1).

Method

Participants

Thirty Washington University undergraduates participated for course credit or monetary compensation. All participants had normal or corrected-to-normal vision and were right-handed.

Design and materials

The design (see Table 4) and materials were identical to those in Experiment 2, with the exception that in all stimulus displays, the target was approximately 50% larger than the flankers (font sizes of 66 and 40, respectively; see Fig. 3 for sample stimuli).

Procedure

The procedure was identical to Experiment 2.

Results

The trimming procedures were identical to those in the previous experiments, with exclusion of RT outliers resulting in <1% of trials being eliminated.

For RT, the 2 (ISPC) × 2 (trial type) within-subjects ANOVA yielded a main effect of trial type, $F(1, 29) = 186.46$, $MSE = 349.38$, $p < .001$, $\eta_p^2 = .865$, indicative of flanker interference ($M = 47$ ms). This main effect was qualified by a significant ISPC × trial type interaction, $F(1, 29) = 10.24$, $MSE = 237.50$, $p = .003$, $\eta_p^2 = .261$, indicative of the ISPC effect (see Fig. 7). Planned comparisons showed that the reduction in flanker interference for the MI, relative to MC, set of items was due to a selective effect of the ISPC manipulation on incongruent trials. MI-incongruent were faster than MC-incongruent, $F(1, 29) = 29.31$, $p < .001$. No difference was found between MI-congruent and MC-congruent trials, $F < 1$. For error rate, the 2 × 2 ANOVA indicated only a main effect of trial type, $F(1, 29) = 7.62$, $MSE < .001$, $p = .01$, $\eta_p^2 = .208$, due to error rate being 1% higher on incongruent than on congruent trials (see Table 3).

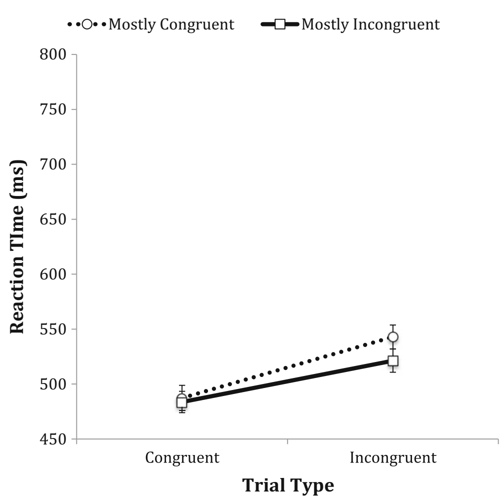

Fig. 7 Mean reaction time (in milliseconds) as a function of trial type for MC and MI items in the arrow-based flanker task in which the target was disproportionately larger than the flankers in Experiment 4. Error bars represent standard errors of the means

Discussion

Experiment 4 utilized a central target stimulus that was disproportionately larger than the flankers to reduce the magnitude of flanker interference while, at the same time, maintaining an arrow-based paradigm in which dimensional imbalance favored the relevant dimension (target). As was expected, flanker interference was reduced (47 ms), relative to Experiment 2 (133 ms), such that the degree of interference "available" to be controlled was comparable to that in the letter-based flanker paradigms used in Experiments 1 and 3 (36–39 ms). Ruling out the possibility that the mechanism supporting ISPC effects depends simply on the magnitude of interference that is available to be controlled, the present findings replicated Experiment 2. The ISPC pattern indicated a selective effect of ISPC on the incongruent trials, consistent with an item-specific control mechanism (Bugg & Hutchison, Experiments 1, 2, and 3; Bugg et al., 2011a, Experiments 1 and 2). Congruent trials were not affected by the ISPC manipulation, despite use of the original two-item set design, which is inconsistent with the operation of a contingency mechanism (Bugg et al., 2011a, Experiment 3; Schmidt & Besner, 2008).

Applying Stroop-based models to the flanker paradigm, one may assume that on MI-incongruent trials, attention to the relevant dimension (target arrow) was enhanced (Blais et al., 2007) and attention to the irrelevant dimension (flankers) was attenuated (Verguts & Notebaert, 2008), relative to MC-incongruent trials. In other words, modulation of flanker processing varied on an item-by-item basis, with presentation of an MI item triggering retrieval of an attentional setting that attenuated processing of the flankers (i.e., using a focused, as opposed to a parallel, strategy; Gratton, Cole, & Donchin, 1992), consistent with the item's history of conflict. The selective effect of ISPC on the incongruent (conflicting) trials is consistent with these models' view that item-specific control is conflict-triggered.

Experiment 5

Collectively, the findings of Experiments 1 through 4 provided support for the dual-ISM account's prediction that the ISPC pattern would be contingency-driven in the letter-based paradigm but would be control-driven in the arrow-based paradigm (Bugg & Hutchison, 2013; Bugg et al., 2011a). Recall that this prediction was based on tectonic theory (Melara & Algom, 2003) and consideration of the role that salience (i.e., ease with which targets and distractors are processed, reflecting their discriminability) plays in dimensional imbalance and, more generally, the relative attractiveness of the target (relevant) and flanker (irrelevant) dimensions. It was assumed that dimensional imbalance would favor attending to the irrelevant dimension in the letter- but not the arrow-based paradigm, due to its salience (i.e., ease of discriminating flankers from the target), which would facilitate use of the distractor–response information carried by this dimension, resulting in a contingency-driven ISPC effect.

The purpose of Experiment 5 was to more directly examine the assumed role of salience in the ISPC pattern obtained in the letter-based flanker paradigm. The original two-item set design was again employed, but a new version of the letter-based flanker paradigm was developed in which the chosen letters within a given set *and* across sets consisted of similar features as in the arrow-based flanker paradigms (see Fig. 3). The letters X and Y served as stimuli in one set, while the letters Z and N served as stimuli in the other set. Reducing salience was expected to decrease attention to the irrelevant dimension (flankers), thereby minimizing the learning of distractor–response relationships and use of contingency learning. In other words, with use of stimuli that, perceptually, were arrow-like, the dual-ISM account predicted that the ISPC pattern would also be more arrow-like (i.e., control-driven; see Fig. 2c), with effects of ISPC approximating those found in Experiments 2 and 4. The contingency account, in contrast, predicted that the ISPC effect would be contingency-driven.

Method

Participants

The participants were 23 Washington University undergraduates who participated for course credit or monetary compensation. All participants had normal or corrected-to-normal vision and were right-handed.

Design and materials

The design (see Table 2) and materials were identical to those in Experiment 1, with the exception that the letters X and Y were assigned to one set, whereas Z and N were assigned to the other set (see Fig. 3 for sample stimuli).

Procedure

The procedure was identical to that in Experiment 1, with the exception that the stimulus–response mapping phase was updated (i.e., on the number pad, 8 = Y; 6 = Z; 2 = X; 4 = N).

Results

The trimming procedures were identical to the previous experiments, with exclusion of RT outliers resulting in <1% of trials being eliminated.

For RT, the 2 (ISPC) × 2 (trial type) within-subjects ANOVA yielded a main effect of trial type, $F(1, 29) = 28.46$, $MSE = 1{,}084.43$, $p < .001$, $\eta_p^2 = .564$, indicative of flanker interference ($M = 37$ ms). It was qualified by an ISPC × trial type interaction, demonstrating the ISPC effect, $F(1, 29) = 12.76$, $MSE = 547.93$, $p = .002$, $\eta_p^2 = .367$ (see Fig. 8). Planned comparisons showed that the effects of the ISPC manipulation were selective to the incongruent trials, $F(1, 29) = 12.56$, $p < .01$, where there was a speeding of 24 ms on MI-incongruent relative to MC-incongruent trials. The ISPC manipulation did not have a significant effect on the congruent trials, $F(1, 29) = 2.27$, $p > .10$. For error rate, there were no significant effects from the 2 × 2 ANOVA (see Table 3 for means).

Discussion

The primary difference between the present experiment and the prior letter-based experiments was the letters chosen to represent the two sets (see Fig. 3). In the present but not the prior experiments, all four letters (X, Y and Z, N) shared overlapping features just like the stimuli (<, > and ∧, ∨) in the arrow-based paradigm. Consistent with the idea that reduced salience minimizes attention to (i.e., the attractiveness of) the irrelevant dimension (flankers) and, consequently, contingency learning (associating responses with particular distractors), the ISPC pattern closely approximated the *control-driven* ISPC pattern that was observed in the prior arrow-based flanker paradigms (Experiment 2 and 4). That is, RTs were speeded on the MI-incongruent relative to MC-incongruent trials, and there was not a significant effect of the ISPC manipulation on the congruent trials (contrary to the

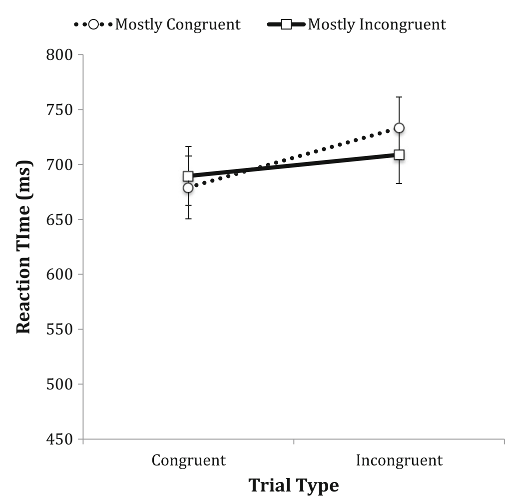

Fig. 8 Mean reaction time (in milliseconds) as a function of trial type for MC and MI items in the letter-based flanker task with X/Y and Z/N as letter sets in Experiment 5. Error bars represent standard errors of the means

contingency account). This is the only letter-based flanker experiment for which this pattern was found. The contrasting findings across experiments provide support for the assumption that salience, as manipulated by altering the discriminability of flankers and targets, plays an important role in modulating the dominance of item-specific contingency learning versus item-specific control in ISPC effects, consistent with the dual-ISM account (Bugget al., 2011a).

In addition to providing evidence to support the assumed role of salience, the present findings also address an alternative explanation of the control-driven ISPC pattern (i.e., Fig. 2c). According to this explanation, the null effect of the ISPC manipulation on congruent trials does not necessarily reflect the null influence of a contingency mechanism. Rather, it may simply be an artifact of designs in which congruent trials are at a functional ceiling (i.e., are already responded to so quickly that there is no room for a contingency mechanism to speed responses farther on MC-congruent trials). In the present experiment, the mean RT for congruent trials was 680 ms. In Experiments 1 and 3, wherein a modulation of RTs on congruent trials was found, the mean RTs on congruent trials were 697 and 616 ms, respectively. These data indicate that there was room for improvement (speeding) on congruent trials in the present experiment but there was still no effect of the ISPC manipulation. The implication is that selective effects of ISPC on incongruent trials, which I have attributed to a conflict-triggered item-specific control mechanism, are not attributable to ceiling effects on congruent trials.

Experiment 6

The purpose of Experiment 6 was to examine another potential account, termed the *perceptual tuning* account, of the qualitatively different ISPC patterns found in the letter-based (Experiments 1 and 3) and arrow-based (Experiments 2 and 4) flanker paradigms. According to this account, the conditions of Experiment 1 (e.g., angular/straight features [K/H] in MC set and curvy letters [S/C] in MI set) may have evoked perceptual tuning to the features of the MC set, thereby masking facilitation of RTs on incongruent trials in the MI as compared with the MC condition.[7] Experiment 2 employed sets of letters that included a combination of angular/straight and curvy features (U/D, and R/L) and an RT speeding on MI-incongruent, relative to MC-incongruent, trials was found (i.e., facilitation was not masked). Perceptual tuning may have contributed to the differing patterns.

A perceptual tuning account may also explain why, in Experiment 5, there was no speeding of RTs on *congruent* trials in the MC as compared with the MI condition in the letter-based flanker paradigm and, similarly, why this same pattern characterized the ISPC effect in the arrow-based flanker paradigms (Experiments 2 and 4). In all three experiments, both sets of stimuli consisted of similar features, which may have minimized perceptual tuning to features of the MC set. Under such conditions, participants may have relied more strongly on a strategy of first detecting whether the flankers and target were identical, and if they were, responding to the first symbol that could be identified, regardless of whether it was the to-be-responded to target or a flanker. Such a strategy might produce a speeding of RTs on all congruent trials (i.e., yielding no difference in RT between MC-congruent and MI-congruent items, as was found).

To examine this account, we utilized the same design and stimuli that were used in the arrow-based paradigm in Experiment 2, but participants were asked to respond by pressing the key that corresponded to the opposite (incompatible) response (e.g., press the left key for the target ">").[8] A pure, perceptual tuning account predicts that the ISPC pattern in the present experiment should be the same as that which was observed in Experiment 2 (i.e., selective effect of ISPC on incongruent trials), because at a perceptual level, the stimuli were identical to those used in that experiment. The dual-ISM account, by contrast, predicts that just the opposite might be found—that is, that attention would be drawn to the distracting flankers and this would facilitate learning of the relationship between particular flankers and responses (i.e., contingency learning). This prediction was based on two considerations. First, tectonic theory posits that an irrelevant dimension is more influential as the average speed of processing the relevant and irrelevant dimensions increases (Melara & Algom, 2003). Relative to Experiment 2, the average speed of processing was expected to increase in the present paradigm due to requiring participants to respond by pressing a key that was incompatible with a natural response tendency (cf. Melara & Mounts, 1993). Consequently, the irrelevant dimension was expected to be more influential. Second, the response instructions were expected to draw attention to the irrelevant dimension because flankers were now perfectly correlated with the correct response on the more challenging incongruent trials. As such, a strategy of attending to and basing responses on the irrelevant dimension and not the target was optimal on *all* trials (i.e., on 50% of trials [incongruent], one fully eliminated the stimulus–response translation demand by using this strategy and, on the

[7] The author is grateful to an anonymous reviewer who suggested the perceptual tuning account and proposed the idea of examining alternative letter sets and using an incompatible stimulus–response assignment in the arrow-based flanker task to examine the account.

[8] One might wonder why this prediction was not (also) tested in the context of the letter-based flanker paradigm used in Experiment 5. I thought it would be difficult for participants to coordinate an incompatible stimulus–response assignment with the stimulus–response translation demands that were already evoked by the task, and this difficulty would likely exacerbate RT slowing and increase error variance.

other 50% [congruent], translation was required regardless of whether the flanker or target was attended; thus, the more optimal strategy was not to switch attention trial to trial but to consistently attend to the flankers).

Method

Participants

Twenty Washington University undergraduates participated for course credit or monetary compensation. All participants had normal or corrected-to-normal vision and were right-handed.

Design and materials

The design (see Table 4) and materials were identical to those in Experiment 2 (See Fig. 3 for sample stimuli).

Procedure

The procedure was identical to that in Experiment 2, except that participants were instructed to respond to the central arrow by pressing the response key that corresponded to the opposite response. For example, if the central arrow was "<," they would press the right response key (6 on the number pad), and if it was "v," they would press the up response key (8 on the number pad).

Results

The trimming procedures were identical to those in the previous experiments, with exclusion of RT outliers resulting in <1% of trials being eliminated.

A 2 (ISPC) × 2 (trial type) within-subjects ANOVA was conducted on the RT data. A main effect of trial type was found, indicating significant flanker interference, $F(1, 19) = 25.79$, $MSE = 2{,}593.39$, $p < .001$, $\eta_p^2 = .576$. This effect was qualified by an ISPC × trial type interaction, $F(1, 19) = 11.50$, $MSE = 771.65$, $p = .003$, $\eta_p^2 = .377$, with the ISPC effect resulting from reduced interference for MI as compared with MC items (see Fig. 9). Planned comparisons indicated that the ISPC manipulation affected RTs on congruent trials, $F(1, 19) = 9.91$, $p < .01$, but did not affect RTs on incongruent trial, $F(1, 19) = 2.72$, $p > .10$. The analysis of error rate revealed no significant effects (see Table 3 for means).

Discussion

The primary finding was a dramatic shift in the ISPC pattern that was found in the prior arrow-based flanker experiments (Experiments 2 and 4). Only in the present arrow-based paradigm was the ISPC pattern characterized by a selective

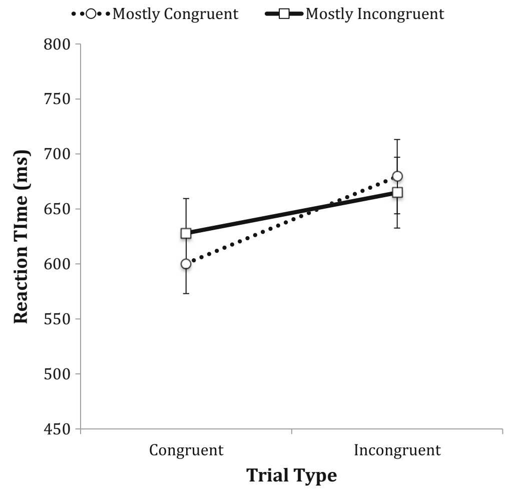

Fig. 9 Mean reaction time (in milliseconds) as a function of trial type for MC and MI items in the arrow-based flanker task with an incompatible stimulus–response assignment in Experiment 6. Error bars represent standard errors of the means

influence of the ISPC manipulation on congruent trials. Shorter RTs were observed on MC-congruent as compared with MI-congruent trials, whereas performance on the incongruent trials did not differ as a function of ISPC. Theoretically speaking, this finding is inconsistent with a perceptual tuning account. That account predicted the same ISPC pattern as that found in Experiment 2 (i.e., selective effect on incongruent trials). By contrast, the finding is consistent with the dual-ISM account, which claims that ISPC effects will be dominated by contingency learning to the extent that attention is drawn to the irrelevant dimension (i.e., flankers are attractive) and the information that dimension conveys (i.e., response contingencies). The fact that flankers were perfectly correlated with the correct response on incongruent trials, along with overall longer RTs, was expected to attract attention to the irrelevant dimension and facilitate use of contingency learning. The selective influence of the ISPC manipulation on congruent trials is consistent with use of this item-specific mechanism (see Fig. 2b.; Bugg et al., 2011a, Experiment 3).

General discussion

In six experiments with flanker paradigms, ISPC effects were examined using the original two-item set design (Jacoby et al., 2003) that allows for item-specific contingency learning or item-specific control to dominate ISPC effects. A primary finding was that despite consistent use of the two-item set design, the effects of ISPC varied across experiments. There was evidence for control-driven, as well as contingency-driven, ISPC effects. This variability was anticipated by the dual-ISM account (Bugg & Hutchison, 2013; Bugg et al., 2011a) but not the contingency account, which expected a consistent pattern of contingency-driven ISPC effects across experiments (Schmidt, 2014; Schmidt & Besner, 2008).[9]

The dual-ISM account predicted that the dominance of one versus the other item-specific mechanism in producing ISPC effects would depend on the relative attractiveness of distractors (the irrelevant dimension) and targets (relevant dimension) in each experiment. According to tectonic theory (Melara & Algom, 2003), correlated, surprising, and/or salient distractors attract attention to the irrelevant dimension, thereby impeding target activation (i.e., attention to the target). Applying tectonic theory to ISPC effects, the dual-ISM account anticipated ISPC effects to be contingency-driven when attention was attracted to the irrelevant dimension but to be control-driven when attention was attracted to the relevant dimension.

To test the dual-ISM account, different flanker stimuli were utilized in Experiments 1 through 5 (see Fig. 3). It was assumed that distractors would be relatively more attractive due to their salience in the letter-based flanker paradigm in Experiments 1 and 3 than in the arrow-based flanker paradigm in Experiments 2 and 4. (Distractors were equally informative and surprising across these experiments, due to use of the two-item set design and equally sized sets of target and distractor stimuli.) In support of the dual-ISM account, the ISPC pattern was consistent with a contingency learning mechanism in the letter-based flanker paradigm and a conflict-triggered item-specific control mechanism in the arrow-based paradigm (Bugg & Hutchison, 2013; Bugg et al., 2011a; cf. Blais et al., 2007; Verguts & Notebaert, 2008).

In further support of the dual-ISM account, a control-driven ISPC pattern was found in Experiment 5 when letter sets comprising similar features were used (as in the arrow-based paradigms), which was intended to reduce the salience of the flankers (i.e., reduce the attractiveness of the irrelevant, relative to the relevant dimension). Moreover, in Experiment 6, a contingency-driven ISPC pattern was found for the same arrow stimuli used in Experiment 2 when an incompatible stimulus–response rule was employed that enhanced the informativeness of the distractors and slowed RTs, both of which were anticipated to attract more attention to the irrelevant dimension (Melara & Algom, 2003).

Collectively, the present findings provide further support for the dual-ISM account's prediction that modulating the degree to which attention is attracted to the irrelevant dimension, either via manipulations of salience (discriminability of flankers/targets) or via changes in distractor correlations, leads to systematic variation in the ISPC pattern (see also Bugg & Hutchison, 2013; Bugg et al., 2011a). The novelty of the present findings in part reflects their emergence in experiments that employed the original two-item set design. In all prior experiments that used this design in the color–word Stroop task, ISPC effects were contingency-driven (Bugg & Hutchison, 2013, Experiment 3; Jacoby et al., 2003; Schmidt & Besner, 2008). This fits with the observation that dimensional imbalance strongly favors the irrelevant dimension in the color–word Stroop task (e.g., Melara & Algom, 2003; cf, Fraisse, 1969) such that control-driven ISPC effects may be difficult, if not impossible, to observe when the two-item set design is employed in that task (see Atalay & Misirlisoy, 2012, for a contingency-driven ISPC effect in a bilingual color–word Stroop task but no evidence for a control-driven effect when dimensional imbalance was assumed to favor the relevant dimension). Importantly, the present findings indicate that contingency-driven ISPC effects are only one possible outcome associated with use of the two-item set design; control-driven ISPC effects are also found with use of this design in both letter- and arrow-based flanker paradigms (see also Bugg et al., 2011a, Experiment 1, for converging evidence from picture–word Stroop).

A limitation of the present experiments is that they lacked an independent measure to assess the assumed manipulations of salience (i.e., varying the attractiveness of distractors relative to targets). For example, as a reviewer pointed out, one might have expected use of a disproportionately larger target in Experiment 4 to increase distractor rather than target salience. If one uses flanker interference as such a measure (i.e., larger = more influence of irrelevant dimension), then the larger interference effects in Experiment 6 than in Experiment 2 lead to the conclusion that attention was attracted to the flankers to a greater extent in Experiment 6, contrary to the assumptions of the dual-ISM account. This measure may not be ideal, however, because the size of the flanker effect is likely to be affected by the potency of the item-specific mechanism that is at play. A contingency learning mechanism might lead to a greater reduction in interference than that produced by item-specific control. The dual-ISM account would be strengthened by future research that addresses this concern.

Alternative accounts

While the dual-ISM account provides a relatively parsimonious explanation of the findings, a number of alternative explanations were also explored. For instance, the finding of a control-driven ISPC effect in the arrow-based paradigm of Experiment 4, in which flanker interference was comparable to the letter-based paradigms of Experiments 1 and 3, ruled out that item-specific control emerged selectively when there was sufficient interference to be controlled (e.g., when dimensional overlap was high; Kornblum & Lee, 1995) or to produce a sufficiently robust

[9] It is unclear whether the contingency account would have predicted a contingency-driven ISPC effect in Experiment 6 given the use of an incompatible stimulus–response rule, which might interfere with typical contingency learning processes.

conflict signal (cf. Blais et al., 2007; Verguts & Notebaert, 2008). Also inconsistent with that explanation was the control-driven ISPC effect observed in the letter-based paradigm of Experiment 5.

An additional explanation that was addressed pertained to the possibility of a functional ceiling on congruent trials in the experiments in which ISPC selectively affected the incongruent trials providing support for item-specific control (Experiments 2 and 4). In Experiment 5, there was room for improvement (speeding) on congruent trials, and the ISPC manipulation still had a selective effect on the incongruent trials, consistent with the prediction of the dual-ISM account. Finally, the findings of Experiment 6 were inconsistent with a perceptual tuning account of this ISPC pattern.

An account that was not directly examined in the present experiments but merits consideration is the temporal learning account. This account posits that conflict-driven modulations of control are due to participants learning when to respond not to differences in conflict between items (lists, etc.) (Schmidt, 2013b). By this account, participants learn to respond rapidly to MC items and are harmed when an MC item is occasionally presented in an incongruent form; conversely, they learn to respond slowly to MI items, and this reduces the benefit when an MI item is presented in a congruent form. If temporal learning were at play in the present experiments, one would have expected a main effect of PC (faster responding to MC than to MI items) across experiments, but that effect was evident only in Experiment 1. Moreover, the temporal learning account does not provide an explanation of the conditions under which learning about MC but not MI items or vice versa should occur, as would be needed to accommodate the differing patterns of ISPC effects that were observed in the present experiments.

Multiple levels of control in the flanker task

From a broader perspective, the present findings are theoretically important in contributing to our understanding of the various levels at which control operates in conflict tasks (cf. Bugg, 2012). Previously, there was evidence for list-level and context-level control in the form of list-wide proportion congruence effects and context-specific proportion congruence effects, respectively, in flanker paradigms (e.g., Corballis & Gratton, 2003; Gratton et al.,1992; King et al., 2012; Lehle and Hübner, 2008; Miller, 1987; Wendt et al., 2008; Wendt & Luna-Rodriguez, 2009). There was also one report of an ISPC effect in a letter-based flanker paradigm (Wendt & Luna-Rodriguez, 2009, Experiment 3). Wendt and Luna-Rodriguez found that their ISPC manipulation affected congruent and incongruent RTs in a letter-based task (although planned comparisons were not reported to determine whether both changes were statistically reliable) and concluded that contingency learning and attention modulation (i.e., control) contributed to the effect. They used a design in which distractor letters were unique to MC and MI conditions but target letters appeared in both sets (i.e., an overlapping sets design). As such, contingency learning could be used to predict responses on MC-congruent but not MI-incongruent trials for which control was presumably operative. The present findings extended the findings of Wendt and Luna-Rodriguez by demonstrating ISPC effects in both letter- and arrow-based flanker paradigms when using the original two-item set design (Jacoby et al., 2003) and, more importantly, characterizing the conditions under which ISPC effects in the flanker task reflect item-specific control (Experiments 2, 4, and 5) versus item-specific contingency learning (Experiments 1, 3, and 6).

The present findings raise the theoretically important question of whether list-wide proportion congruence effects in the flanker task may be partly or wholly item-specific effects in disguise, as has been demonstrated in some Stroop studies (Blais & Bunge, 2010; Bugg, 2014b, Experiments 2 and 3; Bugg, Jacoby, & Toth, 2008, but see Bugg, 2014b, Experiments 1 and 4; Bugg & Chanani, 2011; Bugg, McDaniel, Scullin, & Braver, 2011b; Hutchison, 2011). Some extant findings suggest they may not be (e.g., Mattler, 2006), but to date, no flanker experiment has utilized a list-wide proportion congruence design that permits one to dissociate item-specific effects from global shifts in top-down control that are based on the frequency of conflict within the entire list (e.g., Botvinick, Braver, Barch, Carter, & Cohen, 2001; Braver, Gray, & Burgess, 2007; for examples of such a design, see Bugg, 2014b; Bugg et al., 2011b). Thus, this is an open question for future research.

Conclusion

In summary, the present study provided evidence for qualitatively different ISPC effects when the original two-item set design was employed in letter- and arrow-based flanker paradigms. Consistent with the dual-ISM account, the former yielded a contingency-driven ISPC pattern (Experiments 1 and 3), while the latter yielded a control-driven ISPC pattern (Experiments 2 and 4). The latter pattern challenges the contingency account. Furthermore, it was demonstrated that these patterns could be reversed (i.e., control-driven ISPC effect found in letter flanker and contingency-driven ISPC effect in arrow flanker) by employing task variants that modulated the salience and informativeness of the irrelevant flankers, as predicted by the dual-ISM account (Experiments 5 and 6). These findings expand our understanding of ISPC effects in flanker tasks and the conditions under which ISPC effects can be attributed to item-specific control (i.e., stimulus–attention associations, as opposed to stimulus–response associations). As such, the present study provides further evidence of fast and flexible adjustments in (retrieval of) control settings that minimize attention to distractors upon encountering stimuli that have previously been associated with a high likelihood of conflict. This evidence supports a broader conceptualization of cognitive control that rejects the assumption that attentional settings can only be controlled by supervisory attentional processes (e.g., Bugg & Crump, 2012).

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