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Conflict-Triggered Top-Down Control: Default Mode, Last Resort, or No Such Thing?

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The conflict monitoring account posits that globally high levels of conflict trigger engagement of top-down control; however, recent findings point to the mercurial nature of top-down control in high conflict contexts. The current study examined the potential moderating effect of associative learning on conflict-triggered top-down control engagement by testing the **A**ssociations as **A**ntagonists to **T**op-Down **C**ontrol (AATC) hypothesis. In 4 experiments, list-wide proportion congruence was manipulated, and conflict-triggered top-down control engagement was examined by comparing interference for frequency-matched, 50% congruent items across mostly congruent (low conflict) and mostly incongruent (high conflict) lists. Despite the fact that global levels of conflict were varied identically across experiments, evidence of conflict-triggered top-down control engagement was selective to those experiments in which responses could not be predicted on the majority of trials via simple associative learning, consistent with the AATC hypothesis. In a 5th experiment, older adults showed no evidence of top-down control engagement under conditions in which young adults did, a finding that refined the interpretation of the patterns observed in the prior experiments. Collectively, these findings suggest that top-down control engagement in high conflict contexts is neither the default mode nor an unused (or nonexistent) strategy. Top-down control is best characterized as a last resort that is engaged when reliance on one's environment, and in particular associative responding, is unproductive for achieving task goals.

Keywords: cognitive control, learning, Stroop, aging

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Consider the often-cited experience of arriving at work not able to recall whether you stopped at red lights, signaled before you turned, or followed the speed limit. It may not be a coincidence that this tends to occur when driving a familiar route, a route that is rich with external stimuli that are capable of automatically cuing intimately associated responses and action sequences. That this experience is alarming perhaps reflects our tendency to assume control (of attention, action, etc.) is achieved by endogenous processes (e.g., active representation of goals, will, conscious intention) and our failure to recognize that the environment itself (e.g., external stimuli) acts as a powerful source of control (Hommel, 2007). The present study examines the hypothesis that the default mode may not be for top-down control to be engaged in situations that are typically believed to demand its engagement (e.g., high interference situations such as a busy intersection); rather, top-down control engagement may be directly modulated by the control that is afforded by external stimuli, and as such, might be a last resort in that it emerges when the environment fails to "exert" control.

Questions concerning the processes that are employed to resolve attentional conflict have motivated hundreds of research studies, including many that have employed variations of Stroop's (1935) color-naming task in which conflict occurs when the ink color and word mismatch (e.g., saying "red" in response to the word BLUE written in red ink; MacLeod, 1991). Commonly, the resolution of conflict has been attributed to cognitive control, a putative set of processes that bias attention in a goal-directed fashion by selecting relevant information (e.g., the ink color) and minimizing the processing of irrelevant information (e.g., the word). Quite provocatively, some theoretical accounts have suggested that conflict is not simply an obstacle that must be overcome (via cognitive control) in the course of information processing; rather, conflict also plays the role of the elusive homunculus (Botvinick, Braver, Barch, Carter, & Cohen, 2001; see Cohen, Dunbar, & McClelland, 1990, for a description of a predecessor of this model).

According to this influential view, known as the conflict-monitoring account, a relatively dumb system underlies adjustments in cognitive control (Botvinick et al., 2001). The account posits that the level of response conflict is continuously evaluated and the need for greater cognitive control is signaled by a high degree of conflict. In the model, control is conceived of as engagement of a task-demand unit, which actively represents (maintains) the task-goal. When the level of conflict is high, control is recruited, thereby producing a top-down biasing of attention (e.g., toward the goal-relevant feature; Botvinick et al., 2001).

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Widespread support for the conflict monitoring account's tenet that a high degree of conflict triggers top-down control has been garnered. Biologically speaking, the model has proven to be plausible with multiple studies showing that the anterior cingulate cortex (ACC) is sensitive to the global amount of conflict that is encountered within a given context (e.g., Carter, Botvinick, & Cohen, 1999; Casey et al., 2000; MacDonald, Cohen, Stenger, & Carter, 2000), with detection of a high degree of conflict serving to increase the top-down influence of control regions such as dorsolateral prefrontal cortex (DLPFC) on performance (e.g., Kerns et al., 2004).

At the behavioral level, a key line of evidence supporting the idea that conflict triggers the biasing of attention via top-down control stems from list-wide proportion congruence (LWPC) manipulations. LWPC manipulations vary the frequency of congruent (e.g., RED in red ink) relative to incongruent (e.g., RED in blue ink) trial types within lists (or blocks; Logan & Zbrodoff, 1979) and, as such, vary global levels of conflict. The key finding is that interference is reduced when lists are composed of mostly incongruent trials (i.e., a high level of conflict) compared to mostly congruent trials (i.e., a low level of conflict), a pattern termed the LWPC effect (e.g., Kane & Engle, 2003; Lindsay & Jacoby, 1994; Logan, 1980; Logan & Zbrodoff, 1979; Logan, Zbrodoff, & Williamson, 1984; Lowe & Mitterer, 1982; West & Baylis, 1998).

Puzzling, then, are several recent findings that point to the mercurial nature of top-down control in high conflict contexts. These findings suggest that top-down control engagement is not always evidenced in the face of higher levels of global conflict–participants sometimes show no less interference in a mostly incongruent list than in a mostly congruent list (i.e., Blais & Bunge, 2010; Bugg, Jacoby, & Toth, 2008). These findings provide potential difficulties for the conflict-monitoring account, and stimulate consideration of factor(s) that might moderate engagement of conflict-triggered top-down control.

The purpose of the current study is to test the ***A***ssociations as **A**ntagonists to **T**op-Down **C**ontrol (AATC) hypothesis of conflict-triggered top-down control engagement. The hypothesis is based on the assumption that the availability and use of reliable stimulus–response (S–R) associations (i.e., associations between particular word stimuli and responses in the Stroop task) may be a moderator of conflict-triggered top-down control engagement, that is, the degree to which relatively higher levels of top-down control are triggered in the face of higher (e.g., a mostly incongruent list) compared to lower levels of conflict (e.g., a mostly congruent list). For ease of exposition, henceforth I use the term *top-down control engagement* to refer to there being higher levels of top-down control in the high conflict context compared to the low conflict context. In short, AATC predicts that top-down control engagement will primarily be evident when one cannot rely on use of S–R associations to guide responding on most trials in an effort to achieve task goals (i.e., minimization of Stroop interference).[1]

The AATC hypothesis has its roots in several sources. A primary influence is the work of Algom and his colleagues who have demonstrated that humans detect and utilize correlated dimensions to optimize performance in the color–word Stroop task (Algom, Dekel, & Pansky, 1996; Dishon-Berkovits & Algom, 2000; Melara & Algom, 2003; Sabri, Melara, & Algom, 2001). In other words, participants' attention is drawn to the word because words are often predictive of particular responses (e.g., the color). When proportion congruence is manipulated, as in the current experiments, such correlations are prominent as words tend to be more predictive of the color value in mostly congruent compared to mostly incongruent lists (for review, see Bugg & Crump, 2012). The AATC hypothesis purports that the degree to which one can rely on simple S (word)–R (response) associative learning for response prediction is an important determinant of top-down control engagement. As such, the AATC hypothesis aligns with prior findings demonstrating that use of cognitive control is not obligatory in cognitive control tasks (cf. Hommel, 2007; Mayr, Awh, & Laurey, 2003; Melara & Algom, 2003) for which one might a priori assume the involvement of a top-down supervisory attentional system (Norman & Shallice, 1986). Rather, "control" can sometimes be achieved by what might be considered "noncontrol" mechanisms, such as simple S–R associative learning. The current study aims to expand upon these studies by examining whether engagement of top-down control is modulated by the degree to which a task context promotes reliance on S–R associative learning. In other words, I address the question of whether the learning of and reliance on S–R associations might have an antagonistic influence on top-down control engagement.

Evidence supporting the AATC hypothesis would suggest that the conflict monitoring system may be smarter than previously thought (cf. Botvinick et al., 2001). Rather than indiscriminately triggering top-down control in the face of a high degree of response conflict, the system would be more judicious, engaging top-down control only when goals (e.g., minimizing interference in a Stroop task) could not largely be achieved via simple associative learning of stimuli and responses, a relatively automatic approach to responding. Such a system might be viewed as smarter than a conflict-monitoring system that uniformly engages top-down control whenever conflict is high because it permits the conservation of cognitive (e.g., attentional) resources, thereby increasing their availability for concurrent (e.g., monitoring environment for important cues; Bugg, McDaniel, Scullin, & Braver, 2011; cf. shielding-monitoring dilemma, Goschke & Dreisbach, 2008) or future use.

Consonant with the AATC hypothesis is the view that automatic processes can serve as a powerful "source" of control (i.e., "will" is not the only source; Bargh, 1989; Bargh & Ferguson, 2000; see Hommel, 2007, for review). Indeed, some theorists have posited that humans might prefer to function in a rather "automatic" mode and suggest that relying on the environment as a source of information about goals and corresponding responses is adaptive because conscious control of behavior is dependent upon a limited pool of cognitive resources that may be depleted (Bargh & Chartrand, 1999). Similarly, others have purported that top-down (i.e., proactive) control is resource demanding and metabolically costly (e.g., glucose consuming) and, as such, may be less preferable than reactive modes of responding (Braver, Gray, & Burgess, 2007), such as S–R associative learning.

[1] A reviewer raised the question of whether some top-down control engagement must always be present in both the mostly congruent and mostly incongruent conditions given the high levels of performance (e.g., low error rates) that are routinely observed (including in the present experiments). Although this view seems reasonable, it bears note that a stimulus-driven (item-specific) control process could serve the presumed role of top-down control in minimizing Stroop interference (Bugg et al., 2008; see Bugg, 2012, for review), particularly in paradigms in which proportion congruence is manipulated.

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Experiments 1a through 2b served to test the AATC hypothesis. This hypothesis was contrasted with the predictions of the conflict-monitoring account of Botvinick et al. (2001), which anticipates top-down control engagement to be evident whenever a high level of global conflict is present. These predictions were framed and tested within the context of a current theoretical debate in the cognitive control literature concerning use versus disuse of "list-level control," a top-down control mechanism, in resolving Stroop interference (for review, see Bugg, 2012). I describe this debate prior to presenting the first experiment. Motivated by the findings of the first four experiments, I conclude with a final experiment that addresses the question of whether older adults engage top-down control under conditions in which young adults do so, namely, when S–R associative learning is not a reliable approach for achieving task goals (e.g., minimizing interference) on most trials.

The Debate

The debate centers on the question of whether models that include a top-down control mechanism must be invoked to account for the list-wide proportion congruence (LWPC) effect. It has long been assumed that such a mechanism, referred to here as *list-level control*, is responsible for the effect (e.g., Kane & Engle, 2003; Lindsay & Jacoby, 1994; Logan & Zbrodoff, 1979; Logan et al., 1984; Lowe & Mitterer, 1982; West & Baylis, 1998). List-level control refers to the biasing of attention in a goal-relevant fashion (e.g., away from or toward the distracting word in a Stroop task), based on the global level of conflict within a list (cf. Botvinick et al., 2001), or the expectation that interference is likely (cf. Braver et al., 2007; see De Pisapia & Braver, 2006, for view that such control is sustained in nature). In a mostly incongruent list, list-level control serves to minimize the processing of words that are frequently conflicting. When conflict is infrequent, as in a mostly congruent list, the need for top-down control is low. Consequently, the task-demand unit is less active, and the words are processed more fully.

It has been proposed that the LWPC effect may instead be accounted for by a cognitive control mechanism that operates at a local, item-specific level. According to the item-specific account, the degree of word processing is modulated on a trial-by-trial basis in an item-specific fashion, not in a global fashion based on the degree of conflict within a list (e.g., Blais & Bunge, 2010; Blais, Robidoux, Risko, & Besner, 2007; Bugg et al., 2008). The item-specific account emerged from Jacoby, Lindsay, and Hessels's (2003) discovery of the item-specific proportion congruence (ISPC) effect. They assigned sets of *items* (words) rather than lists to be mostly congruent or mostly incongruent and found that interference was significantly attenuated for mostly incongruent items that tended to produce conflict (e.g., the words GREEN and WHITE appeared 75% of the time in white and green ink, respectively) relative to mostly congruent items that tended not to produce conflict (e.g., the words BLUE and RED appeared 75% of the time in blue and red ink, respectively), a pattern termed the ISPC effect.

A key feature of the ISPC effect is that it arose from a design in which mostly incongruent and mostly congruent items were randomly intermixed, yielding a 50% congruent list. This means that the ISPC effect cannot reflect top-down modulation of word processing based on the global level of conflict within the list (i.e., as in the conflict-monitoring model, Botvinick et al., 2001), as such a mechanism would lead to equivalent levels of interference for mostly congruent and mostly incongruent items. The ISPC effect was instead accounted for by two mechanisms that act poststimulus onset after the item is presented (Jacoby et al., 2003; for reviews, see Bugg, 2012; Bugg & Crump, 2012). One, item-specific control involves rapid modulation of word processing on an item-by-item basis (e.g., less word processing when a mostly incongruent item is presented relative to a mostly congruent item; Bugg & Hutchison, 2013; Bugg, Jacoby, & Chanani, 2011). The second, item-specific S–R associative learning, involves the learning of responses that are most frequently paired with particular words (i.e., referencing the example from the preceding paragraph, learning to respond "white" upon presentation of the word GREEN; Hutchison, 2011; Schmidt & Besner, 2008; cf. Melara & Algom, 2003; Musen & Squire, 1993).

Because the LWPC manipulation perfectly confounds LWPC with ISPC such that all words within a list are mostly congruent (or mostly incongruent) at *both* the item and list levels, it is possible that the LWPC effect reflects the item-specific mechanisms just described (Bugg et al., 2008; Blais & Bunge, 2010). To date, several pieces of evidence have been garnered in support of an item-specific account of the LWPC effect. For instance, Blais et al. (2007) developed an *item-specific conflict-monitoring model*, a modification of Botvinick et al.'s (2001) model, and showed that it can account for not only ISPC effects but also LWPC effects. In the model, item-level conflict was monitored not global levels of conflict. For example, if the item GREEN tended to occur most frequently in white, attention to the color white was heightened whenever GREEN was presented. The model explained the LWPC effect by appealing to differences in item-specific conflict monitoring and the resultant item-specific control adjustments across mostly congruent and mostly incongruent lists (Blais et al., 2007).

Also favoring the item-specific account were the findings from two LWPC studies in which the contributions of list-level, top-down control were dissociated from item-level mechanisms (Blais & Bunge, 2010; Bugg et al., 2008). These studies employed a novel LWPC design that eliminated the confound between LWPC and ISPC for a subset of frequency-matched items (e.g., RED and BLUE) that were 50% congruent regardless of the list in which they were embedded (e.g., mostly congruent or mostly incongruent). The proportion congruency of the lists was determined by a separate set of items (e.g., GREEN and WHITE) that were 75% congruent (in the mostly congruent list) or 25% congruent (in the mostly incongruent list).

Surprisingly, and in contradiction to the globally oriented conflict-monitoring account (Botvinick et al., 2001), interference was equivalent for the 50% congruent items in the mostly congruent and mostly incongruent lists (i.e., there was no LWPC effect), suggesting that globally higher levels of conflict did not trigger top-down control engagement. By contrast, a proportion congruence effect was observed when comparing the 75% and 25% congruent items, items that were mostly congruent or mostly incongruent at the item level, in addition to the global list level. The item-specific conflict-monitoring model readily explained these findings (Blais et al., 2007). When item-specific conflict differed (as in the comparison of 75% to 25% congruent items), so did interference, and when item-specific conflict was equated (as in the comparison of the 50% congruent items across lists), so was interference. Accordingly, one might conclude that (a) engagement of top-down, list-level control does not explain the list-wide proportion congruence effect, and (b) a globally higher degree of conflict is not necessarily associated with greater top-down control. In other words, there may be no such thing as engagement of top-down control in response to high conflict contexts, such as the mostly incongruent condition of Stroop.

These conclusions are tentative, however, because some subsequent studies have found evidence of top-down control engagement in Stroop tasks in which LWPC was manipulated. Using a picture–word Stroop task, Bugg and Chanani (2011) modified the design described above such that four items (rather than two) were used to establish the bias of each list, deeming item-specific associative learning an unreliable method for predicting responses on any incongruent trial (because three incongruent responses were paired equally often with a given word instead of only one, as in the two previous studies). In this case, there was evidence of top-down (list-level) control engagement (i.e., less interference was observed for the 50% congruent items in the mostly incongruent compared to the mostly congruent list; for converging evidence from a six-item color–word Stroop task, see Bugg, McDaniel, et al., 2011). Such findings are readily explained by a top-down shift away from word processing in the list in which levels of conflict were globally high (i.e., mostly incongruent list), consistent with Botvinick et al.'s (2001) conflict-monitoring account but cannot be accommodated by the item-specific conflict-monitoring model. A limitation of these studies, however, is that they did not fully test the proposal that use of top-down control is moderated by individuals' reliance on reliable S–R associations. Neither included a comparison condition in which interference *could* be minimized via use of item-specific S–R associative learning. In addition, alternative explanations such as the larger size of the stimulus sets, which might influence task difficulty, could explain the emergence of top-down control. The present set of experiments addressed these shortcomings, thereby providing the first direct test of the AATC hypothesis.

The current set of experiments aimed to reconcile extant accounts and findings, and refine our understanding of the conditions under which top-down control is engaged under conditions of high conflict. The AATC hypothesis predicts that evidence of top-down control engagement will be weak or nonexistent when reliable S–R associations are present between words and colors, such that participants can utilize them to achieve the task goal on most trials (i.e., minimizing Stroop interference). Across the experiments presented herein, the LWPC effect on 50% congruent trials is utilized as the indicator of top-down control engagement. A reduction in interference for 50% congruent items in a mostly incongruent relative to a mostly congruent list suggests engagement of top-down control, whereas an absence of a difference across lists suggests a lack of (or weak) engagement. Critically, across all five experiments, the global level of conflict was held constant with the mostly congruent lists being 67% congruent and the mostly incongruent lists being 33% congruent. What was varied across experiments is the degree to which reliable S–R associations were present within the lists, a manipulation that allows for the systematic assessment of top-down control across contexts that, according to AATC, differentially demand its engagement.

Experiment 1a

The purpose of Experiment 1a was to establish an initial set of conditions under which top-down, list-level control is observed for 50% congruent items in the color–word Stroop task, a finding that is consistent with the AATC hypothesis and finds some support in the literature (Bugg & Chanani, 2011, picture–word Stroop findings), although it has not yet been replicated. A four-item stimulus set was used to establish the proportion congruency (PC) of the lists and bias participants from relying exclusively on item-specific S–R associative learning (i.e., prediction of responses based on the words). In the mostly congruent list, these biased items were 75% congruent (referred to henceforth as PC-75). In the mostly incongruent list, they were 25% congruent (PC-25). A second set of four items was 50% congruent (PC-50), and the frequency with which these items were presented was matched in the mostly congruent and mostly incongruent list. The combination of the PC-75 and PC-50 items yielded a list that was 67% congruent (mostly congruent) while the combination of the PC-25 and PC-50 items yielded a list that was 33% congruent (mostly incongruent). According to the AATC account, a proportion congruence effect should be observed for both the PC-75/PC-25 items and the PC-50 items, with the effect for PC-50 items uniquely indicating the engagement of list-level, top-down control. These predictions reflect that in this context, the goal of minimizing interference for the majority of items cannot be achieved by relying on S–R associations because, critically, incongruent responses are not predictable in four item sets. AATC's predictions coincide with those anticipated by the globally oriented conflict-monitoring account (Botvinick et al., 2001) but not the item-level conflict monitoring account (Blais et al., 2007), as the latter would predict a proportion congruence effect exclusively for the PC-75/PC-25 items.

Method

Participants. Thirty-six Washington University in St. Louis undergraduates aged 18–22 years participated for course credit or monetary compensation ($10). All participants were native English speakers with normal color vision and normal or corrected-to-normal visual acuity. Half of the participants were randomly assigned to each level of the between-subjects factor, LWPC.[2]

Materials and design. Eight color–words and their corresponding colors were divided into two primary sets (RED, BLUE, WHITE, and PURPLE; PINK, GREEN, BLACK, and YELLOW). Words from one set served as PC-25 *or* PC-75 items, while words from the other set served as PC-50 items (see Table 1). As in previous studies (Blais & Bunge, 2010; Bugg et al., 2008), these sets were not permitted to overlap (e.g., BLUE never appeared in green ink; BLACK never appeared in purple ink). Importantly, this means that a subset of the entire 8 $\times$ 8 matrix of items was presented to each participant. The sets were counterbalanced across participants such that each set served equally often as the PC-25 (or 75) set and the PC-50 set. Mixing the PC-25 items with

[2] Although the current experiments were designed and conducted prior to the recent publication of Abrahamse, Duthoo, Notebaert, and Risko (2013), the findings of their study encourage use of between-subjects designs to investigate factors influencing LWPC effects because the interpretation of differences between mostly congruent and mostly incongruent conditions in within-subject designs can be compromised by the asymmetrical list-shifting effect (i.e., finding that the reduction in the interference effect when shifting from a mostly congruent to a mostly incongruent list is larger than the increase in interference when shifting in the opposite direction).

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Table 1
Frequency of Trial Types Presented in Experiment 1a

Condition	Word	Color							
		Red	Blue	White	Purple	Pink	Green	Black	Yellow
List-Wide PC-33	RED	12	12	12	12				
|C| = −.76	BLUE	12	12	12	12				
	WHITE	12	12	12	12				
	PURPLE	12	12	12	12				
	PINK					12	4	4	4
	GREEN					4	12	4	4
	BLACK					4	4	12	4
	YELLOW					4	4	4	12
List-Wide PC-67	RED	36	4	4	4				
|C| = +.85	BLUE	4	36	4	4				
	WHITE	4	4	36	4				
	PURPLE	4	4	4	36				
	PINK					12	4	4	4
	GREEN					4	12	4	4
	BLACK					4	4	12	4
	YELLOW					4	4	4	12

Note. PC = proportion congruence; List-Wide PC-33 = mostly incongruent list; List-Wide PC-67 = mostly congruent list; |C| = the coefficient of contingency, which reflects the degree to which word and color values are contingent. The sign (+/−) refers to whether the conditional probability of congruent stimuli (+) or incongruent stimuli (−) was relatively large. It was calculated for the entire list (matrix) of items following the formula provided by Melara and Algom (2003). In this table, RED, BLUE, WHITE, and PURPLE are serving the role of PC-25 items (in the List-Wide PC-33 condition) and PC-75 items (in the List-Wide PC-67 condition), whereas PINK, GREEN, BLACK, and YELLOW are serving the role of PC-50 items (in both List-Wide conditions).

the PC-50 items produced a LWPC of 33% (i.e., mostly incongruent). Mixing the PC-75 items with the PC-50 items produced a LWPC of 67% (i.e., mostly congruent). LWPC was manipulated between participants.

The experiment was programmed in E-Prime 1.1. Table 1 displays the frequency with which congruent and incongruent trials from each set were presented in the LWPC-33 and LWPC-67 conditions. A test list of 320 trials was separated into four blocks. One quarter of the total number of trials in each cell of Table 1 was presented in each block. In addition to the congruent and incongruent trials, eight trials consisting of strings of percentage signs (i.e., %%%%) were presented in each block, one in each of the eight ink colors. Stimuli were presented in E-prime's standard color palette ("red," "blue," "white," "purple," "magenta," "green," "black," and "yellow") in 24-point Arial font against a light gray ("silver") background.

Procedure. Participants were individually tested in a small room with the experimenter present. After providing informed consent, participants were instructed to name aloud the ink color the stimuli were printed in as quickly as possible without sacrificing accuracy. Following 12 practice trials, participants completed four blocks of 80 trials. For each participant, stimulus presentation order was randomized within a block. For each trial, the stimulus was presented in the center of the screen until a vocal response was detected at which point the stimulus was erased. The experimenter entered the participant's response via keyboard and the next stimulus was presented 1 s later. Trials on which the voice-key was tripped by extraneous noise or imperceptible speech were considered scratch trials. Following the Stroop task, a computerized version of the Shipley Vocabulary test (Shipley, 1946) was administered. The entire procedure took ~45 min. Reaction time (RT; ms) and error rate were recorded.

Results

RTs less than 200 ms and greater than 3,000 ms were removed for all analyses reported in this article (e.g., Bugg et al., 2008; Bugg & Hutchison, 2013). This resulted in the trimming of less than 1% of the trials in the current experiment. In addition, error trials were excluded from the reaction time analyses. The alpha level was set at .05, and partial eta-squared (η_p^2) is reported as the measure of effect size. Other than those reported, no other effects were significant.

To test the primary predictions, below I report 2 (proportion congruence) × 2 (trial type) analyses of variance (ANOVAs) that were conducted for reaction time and error rate *separately* for the two item types (PC-25/PC-75 items & PC-50 items) following prior studies (Blais & Bunge, 2010; Bugg et al., 2008). Separate analyses were conducted because proportion congruence and item type were not manipulated in an orthogonal fashion (i.e., PC-25 items always occurred in the PC-33 lists and never in the PC-67 lists, and the reverse was true for the PC-75 items). For sake of completeness, I have reported the results of 2 × 2 × 2 omnibus ANOVAs, which include the factor of item type, in Table 2 for this and subsequent experiments. The table also includes the overall (global) Stroop effect (collapsed across item types) for interested readers as all analyses for this and subsequent experiments report Stroop effects separately for each item type.[3]

[3] The correlation between the global SEs for each list (i.e., for mostly incongruent, averaged across the PC-25 items and PC-50 items, and for mostly congruent, averaged across the PC-75 and PC-50 items) and the global (signed) word–color correlation for each list (reflecting the degree to which word and color values were contingent) was sizable (r = .95), consistent with Melara and Algom (2003).

Table 2
Significant Effects From Omnibus ANOVAs for Reaction Time and Error Rate in Each Experiment

DV	Experiment	Effect	*F*	*MSE*	Effect size	Stroop
Reaction time	1a	TT	302.75	1,387	.899	108
		TT × PC	18.58	1,387	.353	
		Item Type × TT × PC	6.36	255	.158	
	1b	Item Type	7.04	1,806	.190	101
		TT	215.64	1,518	.878	
		Item Type × TT × PC	19.1	514	.389	
	2a	TT	183.23	1,805	.843	96
		TT × PC	11.23	1,805	.248	
		Item Type × TT × PC	31.86	289	.484	
	2b	TT	331.01	1,178	.907	104
		TT × PC	22.33	1,178	.396	
		Item Type × TT	22.35	337	.397	
		Item Type × TT × PC	9.38	337	.216	
	3	TT	284.73	3,793	.891	171
		Item Type × TT × PC	10.39	728	.229	
Error rate	1a	TT	42.18	.001	.554	.032
		PC	4.53	.001	.118	
		Item Type × PC	4.38	<.001	.114	
	1b	Item Type × PC	14.48	<.001	.326	.035
		TT	27.44	.001	.478	
		Item Type × TT × PC	11.93	<.001	.285	
	2a	Item Type × PC	5.08	<.001	.130	.029
		TT	41.82	.001	.552	
		TT	53.71	.001	.612	
	2b	PC	8.54	.006	.201	.038
		TT × PC	9.57	.001	.220	
		Item Type × TT	4.20	<.001	.110	
	3	TT	29.00	.001	.453	.024

Note. ANOVA = analysis of variance; DV = dependent variable; TT = trial type (congruent vs. incongruent); PC = the proportion congruency of the list, which was 67% or 33% congruent; Item Type = the contrast of PC-75 or PC-25 items to PC-50 items; Stroop = *global* interference ($RT_{Incongruent} - RT_{Congruent}$) collapsed across item types; RT = reaction time.

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PC-25 and PC-75 items. To examine whether proportion congruency modulated the magnitude of Stroop interference for PC-25 and PC-75 items, a 2 × 2 mixed ANOVA was conducted for reaction time with proportion congruence (PC-25 vs. PC-75) as a between-subjects factor and trial type (congruent vs. incongruent) as a within-subject factor. A main effect of trial type was observed indicative of Stroop interference, the slowing on incongruent (M = 702) relative to congruent trials (M = 591), $F(1, 34) = 302.90$, $MSE = 732.93$, $p < .001$, $\eta_p^2 = .899$. This main effect was qualified by a significant Proportion Congruence × Trial Type interaction, $F(1, 34) = 27.50$, $MSE = 732.93$, $p < .001$, $\eta_p^2 = .447$. Interference was significantly attenuated for the PC-25 (i.e., mostly incongruent; $M = 78$) items relative to the PC-75 (i.e., mostly congruent; M = 145) items (see Table 3).

An identical ANOVA was conducted for error rate (for means see Table 4). Main effects of trial type, $F(1, 34) = 36.50$, $MSE = 0.001$, $p < .001$, $\eta_p^2 = .518$, and proportion congruence, $F(1, 34) = 7.77$, $MSE = 0.001$, $p < .01$, $\eta_p^2 = .190$, were qualified by a significant Proportion Congruence × Trial Type interaction, $F(1, 34) = 7.77$, $MSE = 0.001$, $p = .021$, $\eta_p^2 = .148$. Consistent with the RT data, Stroop interference in error rate was significantly less pronounced for the PC-25 items (M = .02) than the PC-75 items (M = .05).

PC-50 items. Next, performance on the PC-50 items was examined to determine if the magnitude of Stroop interference was modulated by LWPC, independent of any item-specific contribution. A 2 × 2 mixed ANOVA was conducted for reaction time on the PC-50 items with LWPC (LWPC-33 vs. LWPC-67) as a between-subjects factor and trial type (congruent vs. incongruent) as a within-subject factor. A main effect of trial type indicated that performance was slower on incongruent (M = 703) compared to congruent (M = 598) trials (i.e., Stroop interference), $F(1, 34) = 218.18$, $MSE = 908.44$, $p < .001$, $\eta_p^2 = .865$. This main effect was qualified by a significant LWPC × Trial Type interaction, $F(1, 34) = 7.96$, $MSE = 908.44$, $p < .01$, $\eta_p^2 = .190$. Stroop interference was significantly attenuated for the PC-50 items in the LWPC-33 (i.e., mostly incongruent) list ($M = 85$) compared to the PC-50 items in the LWPC-66 (i.e., mostly congruent) list (M = 125; see Table 3).

For error rate, an identical ANOVA revealed a main effect of trial type, $F(1, 34) = 19.21$, $MSE = 0.001$, $p < .001$, $\eta_p^2 = .361$ (see Table 4). Neither the main effect of LWPC or the LWPC × Trial Type interaction were significant (Fs < 1).

Discussion

This experiment represents the first observation of a list-wide proportion congruence effect for PC-50 items in a color–word Stroop task. The importance of this finding is threefold. First, it systematically replicates Bugg and Chanani (2011), who demonstrated a list-wide proportion congruence effect for PC-50 items in a picture–word Stroop task, and in so doing establishes the generality of the effect across Stroop paradigms. These findings demonstrate list-wide proportion congruence effects that cannot be

Table 3
Mean RTs (Standard Deviations) as a Function of Trial Type and Item Type for Each Experiment

			Item type			
					PC-50	
Experiment	Sample	Trial type	PC-75	PC-25	MC	MI
1a	young	Congruent	568 (58)	613 (87)	587 (61)	608 (72)
		Incongruent	713 (77)	691 (96)	712 (78)	693 (83)
		Interference (I − C)	145	78	125	85
		LWPC Effect			40*	
1b	young	Congruent	579 (93)	642 (121)	615 (111)	646 (86)
		Incongruent	709 (127)	715 (106)	709 (131)	754 (101)
		Interference (I − C)	129	73	94	108
		LWPC Effect			−14	
2a	young	Congruent	559 (61)	596 (68)	575 (63)	586 (51)
		Incongruent	695 (82)	653 (57)	678 (72)	673 (64)
		Interference (I − C)	136	57	103	87
		LWPC Effect			15	
2b	young	Congruent	578 (70)	595 (77)	597 (86)	605 (75)
		Incongruent	733 (90)	678 (87)	704 (82)	677 (91)
		Interference (I − C)	155	82	107	72
		LWPC Effect			35*	
3	older	Congruent	716 (101)	744 (193)	733 (124)	735 (187)
		Incongruent	915 (119)	882 (164)	908 (138)	906 (165)
		Interference (I − C)	199	138	175	172
		LWPC Effect			3	

Note. RT = reaction time; I = incongruent; C = congruent; LWPC = list-wide proportion congruence; MC = PC-67 list; MI = PC-33 list. Asterisks indicate that the LWPC effect for PC-50 items was statistically significant.

explained by item-specific mechanisms and establish an initial set of conditions under which the modulation of Stroop interference reflects top-down control as a function of global levels of conflict.

The observation of top-down, list-level control in Experiment 1a is consistent with the AATC hypothesis, which assumes that top-down control is engaged in response to globally high levels of

Table 4
Mean Error Rate (Standard Deviations) as a Function of Trial Type and Item Type for Each Experiment

			Item type			
					PC-50	
Experiment	Sample	Trial type	PC-75	PC-25	MC	MI
1a	young	Congruent	.003 (.005)	.001 (.004)	.004 (.008)	.003 (.008)
		Incongruent	.057 (.050)	.024 (.015)	.033 (.036)	.028 (.032)
		Interference (I − C)	.054	.023	.029	.025
		LWPC Effect			.004	
1b	young	Congruent	.006 (.006)	.006 (.016)	.003 (.007)	.005 (.012)
		Incongruent	.064 (.054)	.025 (.027)	.028 (.026)	.043 (.050)
		Interference (I − C)	.058	.019	.025	.038
		LWPC Effect			−.013	
2a	young	Congruent	.006 (.005)	.007 (.015)	.001 (.004)	.004 (.009)
		Incongruent	.048 (.047)	.023 (.019)	.029 (.026)	.033 (.033)
		Interference (I − C)	.042	.016	.028	.029
		LWPC Effect			−.001	
2b	young	Congruent	.001 (.003)	.002 (.006)	.002 (.006)	.003 (.008)
		Incongruent	.067 (.048)	.024 (.020)	.043 (.036)	.024 (.030)
		Interference (I − C)	.066	.022	.041	.021
		LWPC Effect			−.020	
3	older	Congruent	.003 (.005)	.003 (.008)	.004 (.011)	.003 (.008)
		Incongruent	.031 (.030)	.022 (.022)	.026 (.041)	.030 (.038)
		Interference (I − C)	.028	.019	.022	.027
		LWPC Effect			−.005	

Note. I = incongruent; C = congruent; LWPC = list-wide proportion congruence; MC = PC-67 list; MI = PC-33 list. Asterisks indicate that the LWPC effect for PC-50 items was statistically significant.

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conflict (i.e., Botvinick et al., 2001) when participants cannot simply rely on item-specific S–R associative learning to produce responses on the majority of trials. Because control operates at a global (pathway) level in the model of Botvinick et al. (2001), adjustments in control based on LWPC are expected to produce reductions in interference for the biased items (PC-75 and PC-25) as well as the PC-50 items, as was found, with the latter indicating top-down control engagement. In the current experiment, as in Bugg and Chanani (2011), a larger stimulus set was used to establish the proportion congruency (bias) of the lists (i.e., for the PC-75 and PC-25 items), such that participants could not predict responses on incongruent trials, and therefore could not minimize interference on most trials on the basis of item-specific S–R associative learning. This contrasts with two prior studies that yielded no evidence of top-down control engagement when examining PC-50 items (Blais & Bunge, 2010; Bugg et al., 2008). In those studies, only two items were used to compose each set and responses could be predicted for the majority of incongruent (and congruent) trials using associative learning.

The finding of a LWPC effect for the PC-50 items is inconsistent with the item-specific conflict-monitoring model (Blais et al., 2007). The conflict associated with the PC-50 items is equivalent in the mostly congruent and mostly incongruent lists, yet the magnitude of interference was reduced for these items in the mostly incongruent list. One might posit that the reduction in interference for PC-50 items in the mostly incongruent list reflects sequential control adjustments that carry over from a preceding PC-25 item (i.e., conflict adaptation). As noted by Blais et al. (2007), the item-specific conflict-monitoring model posits, “The word’s impact on the following trial would only be reduced when the stimulus repeats” (p. 1084). Because the words (and colors) used to compose the PC-50 items differ entirely from those used to compose the PC-75/PC-25 sets in this experiment (and all subsequent experiments), such item-specific carry-over effects are not theoretically plausible.

Experiment 1b

The findings of Experiment 1a supported AATC. However, to comprehensively test the AATC hypothesis, it is necessary to determine whether top-down control engagement is evident when participants *can* rely on item-specific S–R associative learning to respond to the majority of trials in the list, including those that are incongruent. AATC predicts that one can eliminate the LWPC effect for the PC-50 items by introducing reliable S–R associations into the PC-75/PC-25 set, thereby establishing a boundary condition for the triggering of top-down control in the face of globally high levels of conflict (Botvinick et al., 2001). The purpose of Experiment 2 was to test this prediction. The four items from the PC-75 and PC-25 sets in Experiment 1a were split into two subsets (pairs of items). For each participant, one of the two subsets served the role of PC-75 or PC-25 items such that responses could be learned and predicted for a large percentage of items in the lists, similar to the original studies of Blais and Bunge (2010) and Bugg et al. (2008), who did not observe a LWPC effect for the PC-50 items. The primary difference between the studies of Blais and Bunge (2010) and Bugg et al. (2008) and the current study is that the PC-50 set in the current study was composed of four items rather than two items, consistent with Experiment 1a. Importantly, this means that the PC-50 items, which were used to evaluate whether top-down control is evident, were identical in all respects across Experiments 1a and 1b. As such, any differences in performance on the PC-50 items between experiments is likely to reflect differences in the composition of the PC-75 and PC-25 set.

Also matched between Experiments 1a and 1b was the overall percentage of conflicting trials in the mostly congruent and mostly incongruent lists. In both experiments, the mostly congruent list was 67% congruent and the mostly incongruent list was 33% congruent. Therefore, comparing the results of Experiment 1a to those of Experiment 1b provides the opportunity to evaluate the AATC hypothesis’s assumption that top-down control, vis-à-vis Botvinick et al. (2001), is not engaged in the presence of high conflict when item-specific S–R associative learning can achieve task goals on most trials. According to the account of Botvinick et al., the LWPC effect for PC-50 trials should be obtained in the present experiment, just like in Experiment 1a.

Method

Participants. The 32 participants were Washington University in St. Louis undergraduates aged 18–21 years who received course credit or monetary compensation ($10) for their participation. All participants were native English speakers with normal color vision and normal or corrected-to-normal visual acuity. Half of the participants were randomly assigned to each level of the between-subjects factor, LWPC.

Materials and design. The materials and design were identical to Experiment 1a with one key exception. In the current experiment, a two-item subset (e.g., RED and BLUE) that produces reliable S–R associations for congruent and incongruent trials, rather than a four-item set that does not, served as the PC-25 or PC-75 items. For the RED, BLUE, WHITE, and PURPLE set, RED and BLUE were paired together in one subset and WHITE and PURPLE were paired together in the other subset. For the PINK, GREEN, BLACK, and YELLOW set, PINK and GREEN were paired together and BLACK and YELLOW were paired together (see Table 5). As an example, as shown in Table 5, in the LWPC-33 condition, *either* RED and BLUE *or* WHITE and PURPLE were presented in a mostly incongruent fashion (as PC-25 items) in combination with the PC-50 items. Each subset was selected equally often to serve the role of PC-25 or PC-75 items (i.e., selected subset was counterbalanced across participants). Note that the PC-50 item set was identical to Experiment 1a—all four words and colors were presented (subsets were not formed). Consequently, a total of six words and their corresponding colors were presented to each participant, instead of eight as in Experiment 1a.

Procedure. The procedure was identical to Experiment 1a.

Results

The RT trimming process resulted in the exclusion of less than 1% of the trials in the current experiment.

PC-25 and PC-75 items. A 2 × 2 mixed ANOVA was conducted for reaction time with proportion congruence (PC-25 vs. PC-75) as a between-subjects factor and trial type (congruent vs. incongruent) as a within-subject factor. A significant main effect of trial type was observed, $F(1, 30) = 163.78$, $MSE = 999.59$, $p <$

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Table 5
Frequency of Trial Types Presented in Experiment 1b

Condition	Word	Color							
		Red	Blue	White	Purple	Pink	Green	Black	Yellow
List-Wide PC-33	RED	24	72						
|C| = −.78	BLUE	72	24						
	WHITE								
	PURPLE								
	PINK					12	4	4	4
	GREEN					4	12	4	4
	BLACK					4	4	12	4
	YELLOW					4	4	4	12
List-Wide PC-67	RED	72	24						
|C| = +.78	BLUE	24	72						
	WHITE								
	PURPLE								
	PINK					12	4	4	4
	GREEN					4	12	4	4
	BLACK					4	4	12	4
	YELLOW					4	4	4	12

Note. PC = proportion congruence; List-Wide PC-33 = mostly incongruent list; List-Wide PC-67 = mostly congruent list; |C| = the absolute value of the coefficient of contingency, which reflects the degree to which word and color values are contingent. The sign (+/−) refers to whether the conditional probability of congruent stimuli (+) or incongruent stimuli (−) was relatively large. It was calculated for the entire list (matrix) of items following the formula provided by Melara and Algom (2003). In this table, RED and BLUE are serving the role of PC-25 items (in the List-Wide PC-33 condition) and PC-75 items (in the List-Wide PC-67 condition), whereas PINK, GREEN, BLACK, and YELLOW are serving the role of PC-50 items (in both List-Wide conditions). Selection of words and colors for the role of PC-25 and PC-75 items was counterbalanced across participants such that for some participants, WHITE and PURPLE were presented in place of RED and BLUE.

.001, $\eta_p^2 = .845$. Reaction time was slower on incongruent (M = 712) relative to congruent (M = 611) trials. This main effect was qualified by a significant Proportion Congruence × Trial Type interaction, $F(1, 30) = 12.77$, $MSE = 999.59$, $p = .001$, $\eta_p^2 = .299$. As in Experiment 1, Stroop interference was attenuated for the PC-25 items (M = 73) relative to the PC-75 items (M = 129; see Table 3).

An identical ANOVA was conducted for error rate. Significant main effects of trial type, $F(1, 30) = 21.86$, $MSE = 0.001$, $p < .001$, $\eta_p^2 = .421$, and proportion congruence, $F(1, 30) = 6.68$, $MSE = 0.001$, $p = .015$, $\eta_p^2 = .182$, were qualified by a significant Proportion Congruence × Trial Type interaction, $F(1, 30) = 5.82$, $MSE = 0.001$, $p = .022$, $\eta_p^2 = .163$. As with the RT data, Stroop interference was attenuated for the PC-25 items (M = .02) relative to the PC-75 items (M = .06; see Table 4).

PC-50 items. A 2 × 2 mixed ANOVA for reaction time was conducted on the PC-50 items to examine whether LWPC modulated Stroop interference, independent of any item-specific contribution. LWPC (LWPC-33 vs. LWPC-67) was the between-subjects factor and trial type (congruent vs. incongruent) was the within-subject factor. A main effect of trial type was observed, $F(1, 30) = 158.47$, $MSE = 1{,}031.99$, $p < .001$, $\eta_p^2 = .841$, indicating that reaction time was significantly slower on incongruent (M = 732) compared to congruent (M = 630) trials. Most critically, and in contrast to Experiment 1a, the LWPC × Trial Type interaction was not significant ($F < 1$). The absence of the LWPC effect suggests that the magnitude of Stroop interference was similar for the PC-50 items in the LWPC-67 (i.e., mostly congruent; M = 94) and LWPC-33 (i.e., mostly incongruent) lists (M = 108; see Table 3).

A similar pattern of results emerged from an identical ANOVA that was conducted for error rate on the PC-50 items (see Table 4). The main effect of trial type was significant, $F(1, 30) = 19.89$, $MSE = 0.001$, $p < .001$, $\eta_p^2 = .399$, and the LWPC × Trial Type interaction was not ($F < 1$).

Cross-Experiment Analysis (Experiment 1a vs. Experiment 1b)

To compare the patterns of performance between Experiments 1a and 1b, 2 (Experiment) × 2 (PC) × 2 (Trial Type) ANOVAs were conducted for RT and error rate, for the PC-25/PC-75 and PC-50 items. For the PC-25/PC-75 items, there were no interactions between Experiment and any other factor for either RT or error rate (Fs < 1). By contrast, for the PC-50 items, the LWPC × Trial Type × Experiment interaction was significant, $F(1, 64) = 6.31$, $p = .015$, $\eta_p^2 = .090$.

Discussion

Consistent with the AATC hypothesis, the LWPC effect was not observed for the PC-50 items in Experiment 1b. Rather, nominally greater interference was observed for the PC-50 items in the mostly *incongruent* list. This finding challenges the globally oriented conflict-monitoring account (Botvinick et al., 2001). The percentage of conflicting trials in the mostly congruent and mostly incongruent lists was identical to Experiment 1a (67% vs. 33%), yet a LWPC effect, indicative of list-level, top-down control was found only in Experiment 1a.

Like the AATC hypothesis, the item-specific conflict-monitoring account (Blais et al., 2007), which purports that control is modulated (and thereby interference) at the item-level based on item-specific conflict, anticipated the absence of a LWPC effect for the PC-50 items in this experiment. Item-specific conflict was equal for PC-50 items in

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the mostly congruent and mostly incongruent lists and accordingly, levels of interference were not expected to differ for these items (Blais et al., 2007). The item-specific conflict-monitoring model has difficulty accounting for the pattern of LWPC effects across Experiments 1a and 1b, however, particularly the evidence for top-down control engagement in Experiment 1a. By contrast, these patterns are consistent with the AATC hypothesis. The primary difference between Experiment 1a and Experiment 1b was the composition of the PC-75/PC-25 items that were used to establish the bias (mostly congruent vs. mostly incongruent) of the list. In the current experiment, only two items were utilized such that participants could rely on item-specific (S–R) associative learning to reliably predict the responses associated with the majority of items within the list (67% of the color word stimuli are of the PC-75 or PC-25 type), and top-down control was not engaged. In Experiment 1a, four items were utilized, undermining the effectiveness of item-specific associative learning for minimizing Stroop interference, and top-down control was engaged.

In both Experiments 1a and 1b, a proportion congruence effect was obtained for the PC-75/PC-25 items. This is important not only from a theoretical standpoint, as all three views (AATC hypothesis; Global Conflict-Monitoring; Item-Specific Conflict-Monitoring) would expect there to be a proportion congruence effect for items that are biased at the item as well as the list level but also because it rules out an alternative explanation of the differences between Experiments 1a and 1b. If, for example, the proportion congruence effect was present for the PC-75/PC-25 items in Experiment 1b but not in Experiment 1a, one might argue that top-down control engagement emerges only when no item-specific (reactive) mechanism is utilized. However, consistent with the AATC hypothesis, the data suggest that reliance on a particular item-specific mechanism, item-specific associative learning, modulated top-down control engagement.

In summary, the findings of Experiments 1a and 1b provide support for the AATC hypothesis. One might suggest an alternative explanation, however. That is, the differing patterns of LWPC effects for PC-50 items across experiments may reflect that there were eight words and associated responses in Experiment 1a and two fewer words and responses in Experiment 1b. It is possible that top-down control was engaged in Experiment 1a because of the larger number of words and possible responses, perhaps due to perceptions of difficulty (i.e., more stimuli, more difficult, greater need for control; Bugg & Chanani, 2011). In Experiments 2a and 2b, I attempted to replicate the primary patterns observed across Experiments 1a and 1b, while holding constant the size of the stimulus and response set. Thus, Experiments 2a and 2b varied in the degree to which use of item-specific S–R associative learning was a reliable means for predicting responses on most trials, but not in the total number of stimuli and responses. If a similar pattern is obtained as in Experiments 1a and 1b, such that modulation of top-down control across the mostly congruent and mostly incongruent lists (i.e., the LWPC effect) is not evident when participants can rely on item-specific S–R associative learning (Experiment 2a) but is evident when they cannot (Experiment 2b), the alternative explanation will be refuted and the AATC hypothesis will be further supported.

Experiment 2a

Eight color words and their corresponding ink colors were utilized. As shown in Table 6, the bias of the lists was again established via the PC-75/PC-25 items, which consisted of a primary set of four color words (and their corresponding colors) broken into two subsets (each consisting of two words and their corresponding colors). Unlike in Experiment 1b, *both* subsets were presented as mostly congruent or mostly incongruent such that all four color words and ink colors appeared during the task. Unlike either of the preceding experiments, the PC-50 set of four color

Table 6
Frequency of Trial Types Presented in Experiment 2a

Condition	Word	Color							
		Red	Blue	White	Purple	Pink	Green	Black	Yellow
List-Wide PC-33	RED	12	36						
|C| = −.88	BLUE	36	12						
	WHITE			12	36				
	PURPLE			36	12				
	PINK					12	12		
	GREEN					12	12		
	BLACK							12	12
	YELLOW							12	12
List-Wide PC-67	RED	36	12						
|C| = +.88	BLUE	12	36						
	WHITE			36	12				
	PURPLE			12	36				
	PINK					12	12		
	GREEN					12	12		
	BLACK							12	12
	YELLOW							12	12

Note. PC = proportion congruence; List-Wide PC-33 = mostly incongruent list; List-Wide PC-67 = mostly congruent list; |C| = the absolute value of the coefficient of contingency, which reflects the degree to which word and color values are contingent; *OR* = odds ratio. The sign (+/−) refers to whether the conditional probability of congruent stimuli (+) or incongruent stimuli (−) was relatively large. It was calculated for the entire list (matrix) of items following the formula provided by Melara and Algom (2003). In this table, RED and BLUE and WHITE and PURPLE are serving the role of PC-25 items (in the List-Wide PC-33 condition) and PC-75 items (in the List-Wide PC-67 condition), whereas PINK and GREEN and BLACK and YELLOW are serving the role of PC-50 items (in both List-Wide conditions).

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words (and their corresponding colors) was also broken into two subsets. Both subsets were presented at a 50% congruent level. The composition of the 50% congruent set in this experiment therefore more closely approximated the composition that was used in the original studies (i.e., a single two-item set; Blais & Bunge, 2010; Bugg et al., 2008). According to the AATC hypothesis, the findings of Experiment 1b should be replicated. A LWPC effect should not be obtained for the PC-50 items because participants can learn to predict the color that each PC-75 or PC-25 pair tends to be presented in for the majority of words within the lists using item-specific S–R associative learning.

Method

Participants. Thirty-six Washington University in St. Louis undergraduates aged 18–23 years participated for course credit or monetary compensation ($10). All participants were native English speakers with normal color vision and normal or corrected-to-normal visual acuity. Half of the participants were randomly assigned to each level of the between-subjects factor, list-wide (LW) proportion congruence.

Materials and design. The materials and design were identical to Experiment 1b with the exception that the precise composition of both the PC-25 (or 75) and PC-50 sets differed. As in Experiment 1b, the subdivided sets were used. However, for the PC-25 or PC-75 set, both subsets of items within the set were presented in accordance with the designated proportion congruency (25% congruent or 75% congruent, respectively). Likewise, for the PC-50 set, both subsets of items within the set were presented and were 50% congruent. As in Experiments 1a and 1b, the sets themselves were not permitted to overlap. Furthermore, the pairs within each subset were not permitted to overlap (e.g., RED never appeared in white ink; GREEN never appeared in yellow ink; see Table 6).

Procedure. The procedure was identical to the preceding experiments.

Results

The RT trimming process resulted in the exclusion of less than 1% of the trials in the current experiment.

PC-25 and PC-75 items. To examine whether the magnitude of Stroop interference was modulated by proportion congruency, a 2 × 2 mixed-subject ANOVA was conducted for reaction time with proportion congruence (PC-25 vs. PC-75) as the between-subjects factor and trial type (congruent vs. incongruent) as the within-subject factor. The main effect of trial type was significant, $F(1, 34) = 177.42$, $MSE = 944.24$, $p < .001$, $\eta_p^2 = .839$. Reaction time on incongruent trials ($M = 674$) was slower than reaction time on congruent trials ($M = 578$). As in the previous experiments, this effect was qualified by a significant Proportion Congruence × Trial Type interaction, $F(1, 34) = 30.07$, $MSE = 944.24$, $p < .001$, $\eta_p^2 = .469$. Stroop interference was attenuated for the PC-25 items ($M = 57$) compared to the PC-75 items ($M = 136$; see Table 3).

For error rate, the 2 × 2 mixed-subjects ANOVA revealed significant main effects of trial type, $F(1, 34) = 19.89$, $MSE = 0.001$, $p < .001$, $\eta_p^2 = .369$, proportion congruence, $F(1, 34) = 4.50$, $MSE = 0.001$, $p = .041$, $\eta_p^2 = .117$, and a Proportion Congruence × Trial Type interaction that approached significance, $F(1, 34) = 3.99$, $MSE = 0.001$, $p = .054$ (see Table 4).

PC-50 items. Next, a 2 × 2 mixed-subject ANOVA was conducted for reaction time on the PC-50 items with LWPC (LWPC-33 vs. LWPC-67) as the between-subjects factor and trial type (congruent vs. incongruent) as the within-subject factor. A main effect of trial type was observed, $F(1, 34) = 141.95$, $MSE = 1{,}149.72$, $p < .001$, $\eta_p^2 = .807$, demonstrating slowing on incongruent ($M = 676$) compared to congruent ($M = 580$) trials. As predicted, the LWPC × Trial Type interaction was not significant ($F < 1$). As in Experiment 1b, the magnitude of Stroop interference was statistically equivalent for the PC-50 items in the list that was mostly incongruent ($M = 87$) and the list that was mostly congruent ($M = 103$; see Table 3).

A similar pattern emerged from an identical 2 × 2 ANOVA that was conducted for error rate on the PC-50 items. The main effect of trial type was significant, $F(1, 34) = 31.73$, $MSE < .001$, $p < .001$, $\eta_p^2 = .483$, but the LWPC × Trial Type interaction was not ($F < 1$; see Table 4).

Discussion

Stroop interference was equivalent for the PC-50 items in the mostly incongruent compared to mostly congruent list, which suggests that top-down control did not vary across the high and low conflict contexts. Like the findings of Experiment 1b, this finding challenges the globally oriented conflict-monitoring account (Botvinick et al., 2001) but is consistent with the AATC account's assertion that when item-specific S–R associative learning can guide responding, engagement of top-down control via global conflict monitoring is preempted.

The absence of a LWPC effect for PC-50 items in this experiment is consistent with the item-specific conflict monitoring account (Blais et al., 2007). Experiment 2b is thus a potentially decisive one in that the goal is to examine whether the LWPC effect once again emerges for an identical set of PC-50 items when participants cannot rely on S–R associative learning to respond to most trials within the list (i.e., the PC-75/PC-25 trials). That pattern, in conjunction with the findings of Experiment 2a, would uniquely support the AATC hypothesis because, although the item-specific conflict monitoring account accommodates the Experiment 2a (and 1b) findings, it does not predict that a LWPC effect should be obtained for the PC-50 items. Importantly, an LWPC effect for the PC-50 items would also rule out accounts based on the number of words and possible responses within a given list, for example those that might posit global, conflict-triggered top-down control engagement to depend on task difficulty (for which number of stimuli and responses may be a proxy).

Experiment 2b

The PC-50 set was identical to that which was used in Experiment 2a. Also identical to Experiment 2a was use of four words and their corresponding colors to form the PC-75/PC-25 set. As such, the total number of words and colors was equated with Experiment 2a. The only change from Experiment 2a was that the PC-75/PC-25 set was not broken into two subsets (see Table 7). Rather, the composition of the PC-75/PC-25 set was such that item-specific S–R associative learning no longer permitted participants to minimize interference on

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Table 7
Frequency of Trial Types Presented in Experiment 2b

Condition	Word	Color							
		Red	Blue	White	Purple	Pink	Green	Black	Yellow
List-Wide PC-33	RED	12	12	12	12				
|C| = −.82	BLUE	12	12	12	12				
	WHITE	12	12	12	12				
	PURPLE	12	12	12	12				
	PINK					12	12		
	GREEN					12	12		
	BLACK							12	12
	YELLOW							12	12
List-Wide PC-67	RED	36	4	4	4				
|C| = +.88	BLUE	4	36	4	4				
	WHITE	4	4	36	4				
	PURPLE	4	4	4	36				
	PINK					12	12		
	GREEN					12	12		
	BLACK							12	12
	YELLOW							12	12

Note. PC = proportion congruence; List-Wide PC-33 = mostly incongruent list; List-Wide PC-67 = mostly congruent list; |C| = the absolute value of the coefficient of contingency, which reflects the degree to which word and color values are contingent. The sign (+/−) refers to whether the conditional probability of congruent stimuli (+) or incongruent stimuli (−) was relatively large. It was calculated for the entire list (matrix) of items following the formula provided by Melara and Algom (2003). In this table, RED, BLUE, WHITE, and PURPLE are serving the role of PC-25 items (in the List-Wide PC-33 condition) and PC-75 items (in the List-Wide PC-67 condition), whereas PINK and GREEN and BLACK and YELLOW are serving the role of PC-50 items (in both List-Wide conditions).

most trials because responses could not be predicted on incongruent trials. The AATC hypothesis therefore predicted that the LWPC effect should be observed for the PC-50 items, replicating the pattern demonstrated in Experiment 1a.

Method

Participants. Thirty-six Washington University in St. Louis undergraduates aged 18–22 years participated for course credit or monetary compensation ($10). All participants were native English speakers with normal color vision and normal or corrected-to-normal visual acuity. Half of the participants were randomly assigned to each level of the between-subjects factor, LWPC.

Materials and design. The materials and design were identical to Experiment 2a with one key exception. The composition of the PC-25 (and PC-75) set differed from the previous experiment in that this set was no longer divided into two subsets. Instead, all four items were presented in each of the four corresponding ink colors in accordance with the designated proportion congruency (see Table 7). Importantly, the composition of the PC-50 set was identical to Experiment 2a.

Procedure. The procedure was identical to the preceding experiments.

Results

In this experiment, the RT trimming process resulted in the exclusion of less than 1% of the trials.

PC-25 and PC-75 items. A 2 × 2 mixed-subject ANOVA was conducted for reaction time with proportion congruence (PC-25 vs. PC-75) as the between-subjects factor and trial type (congruent vs. incongruent) as the within-subject factor. A significant main effect of trial type, $F(1, 34) = 290.59$, $MSE = 870.44$, $p < .001$, $\eta_p^2 = .895$, was observed. Reaction time was slower on incongruent ($M = 705$) compared to congruent ($M = 587$) trials. The Proportion Congruence × Trial Type interaction was also significant, $F(1, 34) = 27.40$, $MSE = 870.44$, $p < .001$, $\eta_p^2 = .446$, as in Experiment 2a and the previous experiments. Stroop interference was attenuated for PC-25 ($M = 82$) compared to PC-75 ($M = 155$) items (see Table 3).

For error rate, the 2 × 2 mixed-subject ANOVA indicated significant main effects of trial type, $F(1, 34) = 48.36$, $MSE = 0.001$, $p < .001$, $\eta_p^2 = .590$, proportion congruence, $F(1, 34) = 11.57$, $MSE = 0.001$, $p < .01$, $\eta_p^2 = .254$, and a Proportion Congruence × Trial Type interaction, $F(1, 34) = 11.79$, $MSE = 0.001$, $p < .01$, $\eta_p^2 = .257$. As with the RT data, Stroop interference was attenuated for the PC-25 items ($M = .02$) relative to the PC-75 items ($M = .07$; see Table 4).

PC-50 items. A 2 × 2 mixed ANOVA was conducted for reaction time on the PC-50 items to examine whether LWPC modulated Stroop interference, independent of any item-specific contribution in this experiment. LWPC (LWPC-33 vs. LWPC-67) was the between-subjects factor and trial type (congruent vs. incongruent) was the within-subject factor. A main effect of trial type was observed, $F(1, 34) = 224.37$, $MSE = 644.44$, $p < .001$, $\eta_p^2 = .868$. Reaction time was prolonged on incongruent ($M = 691$) relative to congruent ($M = 601$) trials. Further, as predicted, a significant LWPC effect was observed, LWPC × Trial Type: $F(1, 34) = 8.72$, $MSE = 644.44$, $p < .01$, $\eta_p^2 = .204$. The magnitude of Stroop interference was attenuated for PC-50 items in the mostly incongruent ($M = 72$) compared to the mostly congruent ($M = 107$) list (see Table 3).

For error rate, the 2 × 2 mixed-subject ANOVA revealed a main effect of trial type, $F(1, 34) = 30.26$, $MSE = 0.001$, $p < .001$, $\eta_p^2 = .471$, and a LWPC × Trial Type interaction that approached significance, $F(1, 34) = 3.13$, $MSE = 0.001$, $p = .084$ (see Table 4).

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Cross-Experiment Analysis (Experiment 2a vs. Experiment 2b)

To compare the patterns of performance between Experiments 2a and 2b, 2 (Experiment) × 2 (Proportion Congruence) × 2 (Trial Type) ANOVAs were conducted for RT and error rate, for the PC-25/PC-75 and PC-50 items. For the PC-75/PC-25 items, there was an experiment × trial type interaction, $F(1, 68) = 4.83$, $p = .031$, $\eta_p^2 = .841$, indicating more RT interference in Experiment 2b (M = 118 ms) than 2a (M = 96 ms). There were no other interactions with experiment for RT (Fs < 1), or error rate (largest $F = 2.62$ for Experiment × Trial Type interaction). For the PC-50 items, there were no interactions with experiment for RT (Fs < 1), or error rate (largest $F = 1.86$ for three-way interaction).

Discussion

The primary finding from Experiment 2b was the LWPC effect for the PC-50 items. This finding is theoretically important for several reasons. First, replicating Experiment 1a, the finding indicates that engagement of top-down (list-level) control was greater in the high (mostly incongruent) relative to the low conflict (mostly congruent) context, a pattern that is consistent with the globally oriented conflict-monitoring account (Botvinick et al., 2001). Second, the finding challenges the item-specific conflict-monitoring account (Blais et al., 2007), as that account would not predict differential interference for items that are equivalent in item-specific conflict (50%). Third, as in all preceding experiments, a proportion congruence effect was observed for the PC-75/PC-25 items, items that were biased at both the item-specific and list-level, a pattern predicted by all three views, including the AATC hypothesis. This pattern is theoretically important because it indicates that the LWPC effect for the PC-50 items is not moderated by the presence of the proportion congruence effect for the PC-75/PC-25 items. Fourth, a comparison of the findings across Experiments 2a and 2b uniquely supports the AATC hypothesis. Contrary to the globally oriented conflict-monitoring account (Botvinick et al., 2001), evidence of conflict-triggered top-down control engagement, as indicated by the LWPC effect on PC-50 items, was selective to Experiment 2b in which participants could not achieve task goals on most trials by simply predicting the responses via item-specific S–R associative learning. The cross-experimental comparison did not, however, indicate that the LWPC effect for the 50% congruent items in Experiment 2b (35 ms) was statistically more robust than that of 2a (15 ms). Next, I report a full cross-experimental analysis that includes the data from all four preceding experiments, thereby increasing the power to detect differences related to the theoretically relevant factor of interest (i.e., the degree to which associative learning affords reliable responding within a given experiment).

Cross-Experiment Analysis (Experiments 1a, 1b, 2a, and 2b)

As a further step toward testing the AATC hypothesis, a cross-experiment analysis was conducted in which the data from the four preceding experiments were combined and 2 × 2 × 2 mixed-subject ANOVAs were conducted for reaction time and accuracy, for the PC-25/PC-75 items and the PC-50 items. Reliability of item-specific S–R associative learning as a means for minimizing interference on most trials was a between-subjects factor, with data from participants in Experiments 1b and 2a categorized as reliable and Experiments 1a and 2b categorized as unreliable. Proportion congruence (PC-25 vs. PC-75) was also a between-subjects factor while trial type was the within-subject factor. There were no significant effects other than those described below.

For the PC-25/PC-75 items, the main effect of trial type for reaction time was qualified by a significant Proportion Congruence × Trial Type interaction, $F(1, 136) = 96.25$, $MSE = 871$, $p < .001$, $\eta_p^2 = .414$, indicating that interference was less robust for the PC-25 items than the PC-75 items. A significant Trial Type × Reliability of Associative Learning interaction was also found, indicating that more interference was observed when associative learning was unreliable (M = 115) compared to when associative learning reliably predicted responses (M = 99), $F(1, 136) = 5.21$, $MSE = 871$, $p = .024$, $\eta_p^2 = .037$. The three-way interaction was not significant ($F < 1$), nor were any other effects.

For error rate, main effects of trial type and proportion congruence were qualified by an interaction between these two factors, $F(1, 136) = 26.26$, $MSE = 0.001$, $p < .001$, $\eta_p^2 = .162$. There was more interference in error rate for the PC-75 items (M = .055) than the PC-25 items (M = .020).

For the PC-50 items, the main effect of trial type was qualified by a significant Trial Type × Proportion Congruence interaction, $F(1, 136) = 7.31$, $MSE = 934$, $p < .01$, $\eta_p^2 = .051$, indicative of the list-wide proportion congruence effect. Less interference was observed for the PC-50 items in the mostly incongruent list (M = 88) compared to the mostly congruent list (M = 107). Most important, there was a significant three-way interaction between reliability of item-specific S–R associative learning, proportion congruence and trial type, $F(1, 136) = 6.03$, $MSE = 934$, $p = .015$, $\eta_p^2 = .042$. When associative learning reliably predicted responses, interference for the PC-50 items in the mostly incongruent (M = 97) and mostly congruent lists (M = 99) was equivalent, suggesting that there was no difference in top-down control engagement as a function of the degree of conflict within a list. However, when associative learning was unreliable, the list-wide proportion congruence effect for the PC-50 items was observed (Ms = 78 and 116 for the PC-50 items in the mostly incongruent and mostly congruent lists, respectively), indicative of conflict-triggered top-down control engagement.

For error rate, other than a main effect of trial type, $F(1, 136) = 98.68$, $MSE = 0.001$, $p < .001$, $\eta_p^2 = .420$, and a Proportion Congruence × Reliability of associative learning interaction, $F(1, 136) = 4.07$, $MSE = 0.002$, $p < .046$, $\eta_p^2 = .029$, for which interpretation is compromised by ceiling effects (no condition with an error rate > .021 and mean differences of no greater than .006 between conditions), no other effects were significant.

Experiment 3

The preceding set of experiments established a set of conditions under which top-down control can be dissociated from item-specific influences. Moreover, and most important, the experiments demonstrated that younger adults engaged top-down control in high conflict contexts under select conditions, namely, when they could not rely on item-specific S–R associative learning to

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achieve task goals on most trials, consistent with the AATC hypothesis. An alternative account might, however, be proposed to explain the pattern of findings across the first four experiments. This account is based on the strength of the word–color correlations in the entire list of trials (mostly congruent vs. mostly incongruent lists) rather than the degree to which the biased PC-75/PC-25 subset yielded reliable prediction of responses.[4] As the work of Melara and Algom (2003) has demonstrated, word–color correlations tend to be stronger within mostly congruent lists than mostly incongruent lists. Thus, the heightened interference that is sometimes observed in mostly congruent relative to mostly incongruent lists may be attributable to the tendency for attention to be drawn to the (more informative) words in the mostly congruent list. Melara and Algom developed |C|, the correlation of contingency, a chi-square based correlation, as an indicator of strength (i.e., the degree to which values of colors are contingent on values of words). Included in Tables 1, 5, 6, and 7 are the |C| values for the mostly incongruent (List-Wide PC-33) and mostly congruent (List-Wide PC-67) lists in the present experiments, with the values indicating the word–color correlation for the entire set of items that composes each list (e.g., PC-25 and PC-50 items, collectively, for the mostly incongruent list). Following Melara and Algom, |C| was allowed to take on positive values when congruent stimuli appeared more frequently than incongruent stimuli, and negative values when incongruent stimuli appeared more frequently than congruent stimuli. If one examines the |C| values for the mostly congruent and mostly incongruent lists within and across experiments, what is apparent is that in the experiments in which top-down control engagement was observed (Experiments 1a and 2b), the absolute value of |C| is stronger, albeit slightly, in the mostly congruent list than the mostly incongruent list. This difference does not exist in the experiments in which there was no evidence of top-down control engagement (Experiments 1b and 2a).

Accordingly, one might posit that the differential correlations in Experiments 1a and 2b created the *appearance* of top-down control engagement when in actuality the difference in interference for the PC-50 items across lists simply reflected that in these experiments, but not in Experiments 1b or 2a, participants' attention was (inadvertently) drawn to the word to a greater degree in the mostly congruent than the mostly incongruent list. In other words, the alternative account implies that there was no "active" top-down control engagement, per se, in Experiments 1a and 2b. While the logic supporting this alternative account is clear, there are a couple of grounds on which to questions its ability to explain the patterns across Experiments 1a–2b. First, the general usefulness of the words, as implied by the absolute value of these correlations, is very high in all experiments (Range = .76 to .88 for all lists). It is not the case that the usefulness of the words is especially low in the experiments in which top-down control engagement was observed or especially high in the experiments in which it was not observed. Second, on the view that the usefulness of the word dictates attention to the word and resultant Stroop effects (see footnote 2 for evidence that the signed correlations did covary with the magnitude of the Stroop effect), one might posit that the nonequivalent biases to attend to (mostly congruent list) versus not attend to (mostly incongruent list) the word in Experiments 1a and 2b may be responsible for the difference in the magnitude of the Stroop effect for the PC-50 items across lists. This view assumes, however, that participants were sensitive to very small differences in the absolute strength of the correlations between mostly congruent and mostly incongruent lists (Difference = .09 for Experiment 1a and .06 for Experiment 2b) and that assumption seems implausible.

One approach to empirically gauging the plausibility of the alternative account and the putative role of (active) top-down control engagement is to examine whether older adults (aged 60+ years) engage top-down control when exposed to the LWPC manipulation that was implemented in Experiment 1a. Older adults present a theoretically interesting case because they are sensitive to word–color correlations such that they show more interference for mostly congruent conditions compared to mostly incongruent conditions (Bugg et al., 2008; Mutter, Naylor, & Patterson, 2005; West & Baylis, 1998). Accordingly, on the view that the LWPC effect for PC-50 items for young adults in Experiment 1a reflected differences in the degree to which the word attracted attention in the mostly congruent list versus repelled attention in the mostly incongruent list, older adults should also demonstrate the LWPC effect. Alternatively, if the LWPC effect for the PC-50 items in Experiment 1a reflected the active engagement of top-down control, with greater control being engaged in the mostly incongruent compared to the mostly congruent list, then older adults should not demonstrate the LWPC effect. This is because older adults are deficient in implementing top-down control (e.g., Gazzaley & D'Esposito, 2007), including when the traditional LWPC manipulation is employed in the Stroop paradigm (Mutter et al., 2005; West & Baylis, 1998). Indeed, West and Baylis (1998) concluded that older adults have difficulty actively maintaining the color-naming goal to strategically guide task performance in the mostly incongruent list (West & Baylis, 1998). Having older adults perform the Stroop task using the design employed in Experiment 1a tested these predictions.

Method

Participants. The 38 older adult participants were recruited from the Washington University in St. Louis Department of Psychology's older adult subject pool. Individuals in this pool are independent and community dwelling. Participants were compensated at a rate of $10.00/hour. The participants were native English speakers with normal color vision and normal or corrected-to-normal visual acuity. Participants were randomly assigned to one level of the between-subjects factor, LWPC. The data from one participant in the LWPC-67 condition, for whom Stroop interference was ~3.5 *SD* above the sample mean, were excluded resulting in 18 participants in the LWPC-33 and 19 participants in the LWPC-67 conditions. There were 21 females and 16 males aged 60–80 years ($M = 70.86$, $SD = 5.67$) who were well educated ($M = 15.31$ years of education, $SD = 2.63$) and whose average health rating was a 3.86 ($SD = 0.80$) on a 5-point Likert-type scale ranging from 1 (*poor*) to 5 (*excellent*). The older adults in the LWPC-67 (mostly congruent; $M = 69.79$, $SD = 5.99$) and LWPC-33 (mostly incongruent; $M = 72.00$, $SD = 5.25$) conditions did not differ in age, $t(35) = 1.19$, $p = .241$; self-reported health ($t < 1$); years of education ($t < 1$); or Shipley vocabulary test

[4] I thank an anonymous reviewer for suggesting that I consider an account based on global word–color correlations.

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scores (*M*s = 36.79 and 35.06, *SD*s = 2.37 and 3.11, for mostly congruent and mostly incongruent conditions, respectively), $t(35) = -1.91$, $p = .064$.[5]

Materials and design. The materials and design were identical to Experiment 1a (see Table 1).

Procedure. The procedure was identical to the preceding experiments.

Results

The RT trimming process resulted in the exclusion of less than 1% of the trials.

PC-25 and PC-75 items. A 2 × 2 mixed-subject ANOVA was conducted for reaction time with proportion congruence (PC-25 vs. PC-75) as the between-subjects factor and trial type (congruent vs. incongruent) as the within-subject factor. A significant main effect of trial type revealed a 169-ms Stroop effect, $F(1, 35) = 272.16$, $MSE = 1{,}927.17$, $p < .001$, $\eta_p^2 = .886$. This main effect was qualified by a significant Proportion Congruence × Trial Type interaction, $F(1, 35) = 8.88$, $MSE = 1{,}927.17$, $p < .01$, $\eta_p^2 = .202$, indicative of a proportion congruence effect for the PC-25/PC-75 items. Less interference was observed for the PC-25 items ($M = 138$) compared to the PC-75 items ($M = 199$; see Table 3).

For error rate, only the main effect of trial type was significant, $F(1, 35) = 27.97$, $MSE < .001$, $p < .001$, $\eta_p^2 = .444$. Error rate was higher on incongruent ($M = .026$) compared to congruent trials ($M = .003$; see Table 4).

PC-50 items. Next, a 2 (LWPC-33 vs LWPC-67) × 2 (Trial Type) mixed ANOVA was conducted for reaction time on the PC-50 items to examine whether LWPC modulated Stroop interference, independent of any item-specific contribution, for older adults. The main effect of trial type was significant, $F(1, 35) = 214.21$, $MSE = 2{,}594.23$, $p < .001$, $\eta_p^2 = .860$, indicating a 173-ms Stroop effect. However, LWPC did not interact with trial type ($F < 1$). Stroop interference was equivalent for PC-50 items in the LWPC-33 (mostly incongruent; $M = 172$) and LWPC-67 (mostly congruent) lists ($M = 175$; see Table 3).

For error rate, the same pattern was found as for RT. The main effect of trial type was significant, $F(1, 35) = 13.20$, $MSE = 0.001$, $p = .001$, $\eta_p^2 = .274$. Error rate was higher on incongruent ($M = .028$) compared to congruent trials ($M = .004$). The interaction of proportion congruence and trial type was not significant ($F < 1$; see Table 4).

Discussion

There were two key findings. First, unlike the young adults in Experiment 1a (and Experiment 2b), older adults showed equal amounts of Stroop interference for PC-50 items in the mostly incongruent and mostly congruent lists. This finding is incompatible with the alternative word–color correlation account considered earlier. If that account has merit for explaining the present patterns, older adults, like young adults, should have shown an LWPC effect for PC-50 items given their intact sensitivity to and use of word–color correlations (Bugg et al., 2008; Mutter et al., 2005; West & Baylis, 1998). However, they did not. The absence of the LWPC effect for the PC-50 items for older adults is, by contrast, consistent with the view that this population is impaired in actively engaging top-down control in the face of a high degree of response conflict (West & Baylis, 1998).

What are the implications of this finding for the AATC hypothesis? The implications must be evaluated in light of not only the current finding but also a related finding from past research. Bugg et al. (2008) found that older adults, like young adults, showed less interference for PC-25 compared to PC-75 items but showed no LWPC effect for the PC-50 items. Recall that in their study, two items served the role of PC-50 items and two served the role of PC-75/PC-25 items. This pattern provided preliminary support for the AATC hypothesis, but it remained unknown (until now) whether a LWPC effect for the PC-50 items would be obtained for older adults if item-specific S–R associative learning could *not* be used to minimize interference on most trials. That older adults showed equal amounts of interference in the mostly congruent and mostly incongruent lists in the present experiment suggests that, despite the "optimal" conditions for triggering top-down control engagement (according to AATC), there was no evidence for such engagement. One interpretation is that the AATC hypothesis is valid for young adults, but not for populations such as older adults who are deficient in implementing top-down control (e.g., Gazzaley & D'Esposito, 2007; West & Bayis, 1998). In other words, removing the associative information afforded by the environment (external stimuli) does not lead to the emergence of top-down control for populations that could not otherwise engage it.

A second key finding from the present experiment, however, suggests that a less restrictive version of the AATC hypothesis may characterize top-down control engagement in older adults. Older adults showed less interference for the mostly incongruent (PC-25) items compared to the mostly congruent (PC-75) items, which is indicative of an item-specific proportion congruence effect (given the absence of list-level control; see also Bugg & Hutchison, 2013, for evidence that item-specific proportion congruency effects reflect item-specific control and not simply item-specific associative learning when four items are used to create the PC bias).[6] In other words, the relatively automatic modulation of word processing based on the degree to which an item has previously been interfering, appears unimpaired in older adults. This suggests that older adults, though impaired in engaging top-down control, may have intact item-specific control (cf. Verhaeghen, 2011), extending prior studies that have demonstrated intact item-specific S–R associative learning in this population (Bugg et al., 2008).

[5] Shipley scores were very similar for the older adults in this experiment and the young adults in Experiments 1a ($M = 33$), 1b ($M = 34$), 2a ($M = 34$), and 2b ($M = 34$).

[6] Although not a central theoretical issue in the present study, the finding of an ISPC effect for older adults is of additional importance because it rules out an alternative account of the overall pattern of findings in Experiment 3. That account refers to sensory loss, in particular decreased color perception for older adults, which has been shown to increase Stroop interference in this population (Ben-David & Schneider, 2009). Had the older adults not demonstrated the proportion congruence effect for the PC-75/PC-25 items, one might have posited that color perception difficulties interfered with color naming or prohibited participants from distinguishing the mostly congruent items from the mostly incongruent items, thereby precluding control adjustments from being made at either the list or item-specific level.

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For older adults, it may be that conflict-triggered top-down control engagement occurs only when the environment is a completely useless source of information for achieving a task goal such as minimizing interference. Reliable S–R associations were present in the prior study, and engagement of top-down control was not evidenced for older adults (Bugg et al., 2008). In the current study, word-proportion congruency correlations, which cue the appropriate item-specific control settings for resolving interference (i.e., such as "rapid attenuation of word processing" if the item is a mostly incongruent word, which can be thought of as a stimulus-attention association; see Bugg & Crump, 2012; Crump & Milliken, 2009), were present and engagement of top-down control was not evidenced for older adults. Thus, it may be that associations more generally, be they in the form of S–R associations or stimulus-attention associations, preclude engagement of top-down control for older adults. Consistent with this idea, Spieler, Mayr, and LaGrone (2006) found that older adults rely more heavily on external cues in situations in which optimal responding can alternatively be achieved via internal settings (e.g., top-down control).

General Discussion

The purpose of the current study was to develop and test the AATC hypothesis, which predicts that conflict-triggered top-down control engagement is minimal when one can rely on the environment to reliably predict responses on the majority of trials. Stated differently, when task goals can largely be achieved via item-specific S–R associative learning (e.g., the prediction of a response that is correlated with a word in the Stroop task), the contributions of top-down control are minimal even if global levels of conflict are high. The findings across the first four experiments with young adults supported the AATC hypothesis, and in so doing, reconciled prior discrepant findings concerning the role of top-down control in the LWPC effect (e.g., Blais & Bunge, 2010; Bugg & Chanani, 2011; Bugg et al., 2008; Bugg, McDaniel, et al., 2011; Hutchison, 2011). As summarized in Table 8, the LWPC effect for the PC-50 items, the indicator of top-down control engagement, was selectively found in Experiments 1a and 2b. It is these experiments for which the composition of the PC-75/PC-25 items, which made up 67% of all trials and established the overall bias (mostly congruent or mostly incongruent) of a list, did not permit participants to minimize interference by predicting the responses that were associated with words on most trials. This contrasts with Experiments 1b and 2a, which permitted the prediction of responses for the majority of trials via item-specific associative learning. In these experiments, evidence of top-down list-level control was absent or weak, suggesting that global, attentional biases were not established for the mostly congruent and mostly incongruent lists. Presumably, participants instead resolved interference for PC-50 items in a transient fashion, poststimulus onset. The equivalency of interference effects for these items in the mostly congruent and mostly incongruent lists of Experiments 1b and 2a suggests these poststimulus control processes were similarly effective in each list, which is not surprising given that the PC-50 items were 100% identical across the two lists.

There are several design features and patterns of data that rule out alternative explanations of the differences in top-down control (i.e., the LWPC effect) across the first four experiments. First, the composition of the PC-50 items was identical in Experiments 1a and 1b and in Experiments 2a and 2b (see Table 8), thereby pointing to the composition of the PC-75/PC-25 items and not the PC-50 set as the locus of the differences in the LWPC effect (i.e., marker of top-down control). Second, the percentage and frequency of incongruent (relative to congruent) trials within each list was matched across experiments. This means that objective levels of global conflict were equivalent in Experiments 1a through 2b, thus ruling out the frequency with which conflicting trials were experienced as an explanation for the differing levels of top-down control engagement across experiments.[7] Third, because it is the difference in conflict between the mostly congruent and mostly incongruent lists that is presumed to be responsible for the differential engagement of top-down control (i.e., reduction in interference in the mostly incongruent compared to the mostly congruent list for PC-50 items), it is important to note that a Proportion Congruence × Trial Type interaction was found for the PC-75/PC-25 items in all experiments. Additionally, the magnitude of this effect was highly similar in three of the four experiments (Experiments 1a, 2a and 2b; see Table 8), suggesting that the subjectively greater experience of interference (i.e., conflict) in the mostly incongruent relative to the mostly congruent list was a signature of the present experiments. This means that variability in the proportion congruence effect for the PC-75/PC-25 items, in terms of its presence/absence or size, is not likely the source of variations in the LWPC effect (i.e., top-down control engagement) across experiments. Supporting this conclusion was the cross-experiment analysis showing that the proportion congruence effect (Proportion Congruence × Trial Type interaction) for the PC-75/PC-25 items was statistically equivalent in the experiments for which item-specific S–R associative learning was a reliable strategy for predicting responses on most trials (68-ms effect on average in

[7] An interested reader might be curious about the presence of sequential effects (i.e., conflict adaptation effects), and there putative role in the patterns that were observed across the first four experiments. While I report sequential analyses below, it is important to note that the current study was not designed to examine sequential effects and therefore no attempt was made to control for feature repetitions that muddy interpretation of such effects, and no attempt was made to ensure a sufficient number of observations for all possible combinations of trial sequences. Thus, the following analyses should be interpreted with caution. The factor Previous Trial Type was added to the standard ANOVA used to examine performance on the PC-75/PC-25 and PC-50 items resulting in a 2 (Previous Trial Type) × 2 (Trial Type) × 2 (Proportion Congruence) mixed-subjects ANOVA with proportion congruence being the only between-subjects factor. To summarize, for all experiments, and all item types, there was evidence for a Previous Trial Type × Trial Type interaction ($ps \leq .07$) for RT showing less interference following incongruent than congruent trials, and the error rate data did not contradict the RT patterns. The exception was the PC-50 items in Experiment 1a for which there was no interaction between previous trial type and trial type for either RT ($F = 1.11$, $p = .30$) or error rate ($F = 2.01$, $p = .17$). Critically, the three-way interaction was not significant in any case. Moreover, when Experiment was included as a factor, the sequential effects in RT (or error rate) did not interact with Experiment for either item type ($Fs < 1$) for the comparison of Experiments 1a and 1b or for the comparison of Experiments 2a and 2b. Finally, when the factor Experiment was replaced with the factor Reliability of Associative Learning (High vs. Low), thereby comparing the data from Experiments 1a and 2b (Low) to that of Experiments 1b and 2a (High), the sequential effects did not interact with this factor (either alone or in combination with proportion congruence) for either item type ($Fs < 1$ for RT, and $Fs < 2.37$, $ps > .12$, for error rate).

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Table 8
Summary of Findings for Experiments 1a Through 2b

Experiment	PC-75/PC-25 items				PC-50 items	
	Composition	PC × TT	Effect size	Stroop	Composition	PC × TT (LWPC)
1a	1 set of 4 words/colors	yes	.447	111	1 set of 4 words/colors	yes
1b	1 set of 2 words/colors	yes	.299	101	1 set of 4 words/colors	no
2a	1 set of 4 words/colors broken into two pairs	yes	.469	96	1 set of 4 words/colors broken into two pairs	no
2b	1 set of 4 words/colors	yes	.446	118	1 set of 4 words/colors broken into two pairs	yes

Note. PC × TT = proportion congruence by trial type interaction; LWPC = list-wide proportion congruence. The effect size pertains to the PC × TT interaction. Stroop refers to interference ($RT_{Incongruent} - RT_{Congruent}$). RT = reaction time.

Experiments 1b and 2a) and those for which it was not (70-ms effect on average in Experiments 1a and 2b).

Theoretical Relevance and Modeling

The pattern of findings across experiments is theoretically important in that it suggests a smarter conflict-monitoring system than previously thought. The data suggest a system for which the default mode is not to engage top-down control whenever there is a globally frequent occurrence of conflict (i.e., a high percentage of incongruent trials), contrary to the globally oriented conflict-monitoring account (Botvinick et al., 2001). Neither is it the case that there is no such thing as engagement of top-down control on the basis of global levels of conflict, as some extant models (Blais et al., 2007) and findings (Blais & Bunge, 2010; Bugg et al., 2008) have suggested. Rather, the data indicate that globally high levels of conflict sometimes trigger engagement of top-down control, and the AATC hypothesis predicted the conditions under which this engagement would occur. Young adults showed little to no evidence of increased top-down control in high relative to low conflict contexts when they were able to rely on item-specific S–R associative learning to respond to the majority of trials within a list (e.g., Experiments 1b and 2a). By contrast, when this was not a reliable approach, due to there being multiple, possible responses on incongruent trials (i.e., a four-item biased set), young adults showed greater use of top-down control in the high relative to the low conflict context (e.g., LWPC effect in Experiments 1a and 2b).

One might ask the question of whether, as currently described, the AATC hypothesis is too restrictive. For older adults, as discussed earlier, it appears that might be true. Older adults did not show evidence of top-down control engagement under conditions that were identical to those used in Experiment 1a, in which young adults did engage top-down control. As discussed following Experiment 3, those conditions were not ones in which the environment was completely useless. Indeed, there were correlations between words and proportion congruency levels such that stimulus-attention associations could be learned and utilized, and older adults did so as evidenced by the item-specific proportion congruence effect that was found for the PC-75/PC-25 items. For older adults, then, it could be the case that they simply cannot engage top-down control to minimize Stroop interference *or* their dependence on environmental cues (cf. Spieler et al., 2006) makes them less apt to engage top-down control in the face of any useful information associated with stimuli, including that which does not lead to the reliable prediction of responses on most trials. Could a less restrictive version of AATC also account for young adults' performance across experiments? The version just described could not. In all experiments, word–proportion congruency associations were present in the biased PC-75/PC-25 set of items but contrary to the less restrictive version, top-down control was observed for the PC-50 items in two of these experiments.

One interpretation of the current patterns is that top-down control plays a smaller role when goals can largely be achieved via a perhaps simpler, and less demanding strategy (cf. Braver et al., 2007) that permits the conservation or distribution of resources but is triggered when goals cannot be achieved via this route. As such, top-down control engagement in high conflict contexts may be best characterized as a last resort. The conflict-monitoring model of Botvinick et al. (2001) could be modified to capture this idea (and the current data), for example by adding a gate to the model that closes when reliable S–R associations are detected and utilized (e.g., via a S–R accumulator), such that anterior cingulate signals to prefrontal cortex are muted. Of course, this idea raises important questions about the point at which the gate would close (e.g., how much item-specific S–R learning is necessary before the gate closes and any conflict-triggered top-down control engagement ceases). Item-specific proportion congruency effects develop extremely quickly (i.e., within 16 trials; Jacoby et al., 2003) when item-specific S–R associative learning contributes to the effects. Accordingly, it is possible that conflict-triggered engagement of control never developed or faded out extremely rapidly (i.e., the gate closed quickly) following relatively few trials in contexts such as those in Experiments 1a and 2b.

I have focused primarily on the relationship between AATC and two extant models, the globally oriented (Botvinick et al., 2001) and item-specific (Blais et al., 2007) conflict monitoring models. Additionally relevant is the work of Verguts and Notebaert (2008, 2009), who proposed the item-specific adaptation-by-binding account. This account posits that features of a stimulus such as those associated with the word and color are bound to a task-level representation to respond to the color. Task-relevant connections are strengthened (and task-irrelevant connections weakened) at the item level when conflict is high (because Hebbian learning is enhanced by conflict), thereby increasing the influence of the task demand unit for a given item. As such, stronger connections exist for mostly incongruent than mostly congruent items, and interference is less robust for mostly incongruent items, which readily

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explains the proportion congruence effect for the PC-25/PC-75 items in the current experiments. According to this account, control intervenes to place more emphasis on the task-relevant route when one cannot rely on prior learning (via task-irrelevant features), such as when new stimuli are encountered (e.g., new word–color pairings). While both the AATC hypothesis and the item-specific adaptation-by-binding account address the putative roles of learning and control in performance of conflict tasks, it is unclear how the latter would explain the *differential* LWPC effects for PC-50 items across Experiments 1a through 2b. In all experiments, prior learning of the word–color associations for the PC-25/PC-75 items could not be relied upon when responding to the different word–color pairings that were encountered for the PC-50 items. The PC-50 items were composed of words and colors that were distinct from the PC-25/PC-75 items. Given these task characteristics, it seems that the item-specific adaptation-by-binding account would have anticipated an equivalent conflict-driven shift in controlling attention toward the relevant information for the PC-50 items across experiments.

Also meriting comment is the recently proposed temporal learning account, which posits that conflict-driven modulations of control reflect adaptations to “time on task” and not conflict per se (Schmidt, 2013). According to this view, LWPC effects are due not to differences in conflict between lists (or items); rather, they reflect differences in when participants have learned to respond. In a mostly congruent list, one learns to respond rapidly, which penalizes the occasional incongruent trials. In a mostly incongruent list, one expects to respond more slowly, which reduces the benefit for congruent trials. As Schmidt (2013) predicted, “The result, even for contingency-unbiased items, is a reduced Stroop effect” (p. 619). In the current study, those items were the PC-50 items, and the temporal learning account does not explain why the reduced Stroop effect for the PC-50 items in the mostly incongruent (compared to the mostly congruent) list was limited to a subset of the present experiments (nor why the effect was not obtained in some prior studies; Blais & Bunge, 2010; Bugg et al., 2008).

Applying the views of Egner (2008) or Logan (1980) appears instructive for interpreting the current data. Egner suggested that there are multiple conflict-driven control mechanisms that support performance (Egner, 2008). Applying Egner’s descriptions, item-specific S–R associative learning might be viewed as a mechanism that exerts control over conflict (i.e., counter to the idea of it being a “noncontrol” mechanism; cf. Braem, Verguts, & Notebaert, 2011). Conflict-driven control via item-specific S–R associative learning and conflict-driven control via top-down adjustments are seemingly antagonistic—when the first is strongly operative, the second is not, as in Experiments 1b and 2a. By contrast, conflict-driven control via top-down adjustments appears to be capable of operating in parallel with conflict-triggered item-specific control mechanisms (i.e., use of stimulus-attention associations; e.g., Bugg & Crump, 2012), as in Experiments 1a and 2b. With respect to Logan’s model, the differential LWPC pattern for the PC-50 items across experiments could be reflected in differential weights being assigned to the attentional (strategic) component and automatic component. Whereas Logan described his LWPC findings as demonstrating the extent to which automatic effects could be overcome by attention, the same model, if applied to the present data, seems sufficiently flexible to demonstrate the modulation of attentional weights (i.e., top-down control) depending on automatic effects (S–R associative learning), including instances where attention is “overcome” by automatic effects (Experiments 1b and 2a).

Indices of Top-Down Control and Factors Influencing Engagement

In the current study, I examined the LWPC effect for 50% congruent items in the color–word Stroop task as the indicator of top-down control engagement (cf. Bugg & Chanani, 2011). In a recent review, Awh, Belopolsky, and Theeuwes (2012) advocated for greater theoretical precision in identifying those empirical patterns (measures) that can be attributed to top-down cognitive control. They noted that the extant bottom-up/top-down dichotomy is insufficient (cf. Bugg & Crump, 2012), and urged researchers to rule out not only bottom-up influences as traditionally defined, but additionally the involuntary or lingering effects of selection history, before concluding that a measure reflects top-down control. By selection history, they referred to attentional biases that reflect prior experiences with stimuli to which they are currently responding. Because the PC-50 items were perfectly matched across the mostly congruent and mostly incongruent lists (in all experiments), including in frequency, and shared no features with the biased PC-25/PC-75 items (e.g., were of a different color and were different words), any effects of selection history should have been equated across lists. As such, the LWPC effect for the PC-50 items appears to be a valid indicator of top-down control engagement.

The identification of additional indicators of top-down control engagement will facilitate tests of the generality of the AATC hypothesis. The most obvious extension is to other conflict paradigms in which LWPC manipulations have been employed, such as the flanker task (Gratton, Coles, & Donchin, 1992; Wendt & Luna-Rodriguez, 2009). Extending the AATC hypothesis further, it would be advantageous to find a comparable indicator of top-down control engagement in paradigms that examine other domains of cognitive control such as task switching. One fruitful possibility is to examine reliance on S–R rules versus task rules (which might be thought of as a top-down strategy). In a recent review, Dreisbach (2012) detailed the unexpectedly good performance (e.g., no switch costs) that can result from use of S–R rules but showed that task-rules outperform S–R rules when susceptibility to irrelevant features is considered. Examining the extent to which use of task-rules is moderated by the opportunity to utilize reliable S–R rules might be one way to extend the AATC hypothesis. Finally, the AATC hypothesis may also find merit in the domain of memory retrieval, where cognitive control processes are vital. Bunge, Burrows, and Wagner (2004) found that the ability to recollect learned information via retrieval of strong associations was associated with reduced demands on top-down control, as indicated by anterior cingulate and dorsolateral prefrontal cortex activation. When the task required retrieval of weak associations, engagement of top-down control was more prominent, which accords nicely with the AATC hypothesis.

The present set of experiments examined one possible factor (ability to achieve task goals by relying on item-specific S–R associative learning) that moderates engagement of conflict-triggered top-down control. The current data were supportive. Importantly, the AATC hypothesis also accounts for other extant findings. In addition to those already discussed (e.g., Blais & Bunge, 2010; Bugg et al., 2008), the finding that the LWPC effect

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and asymmetrical list shifting effect (i.e., reduction in interference when shifting from a mostly congruent to a mostly incongruent list is larger than the increase in interference when shifting in the opposite direction) were limited to biased items and were not found for PC-50 items in an experiment in which two-item sets were used and item-specific S–R associative learning was a reliable approach, is also consistent with the AATC hypothesis (Abrahamse et al., 2013). There are additionally some extant patterns that appear to challenge AATC. Wendt and his colleagues cleverly demonstrated a conflict-dependent perceptual filtering effect in a paradigm in which participants switched back and forth between a visual search and flanker task (Wendt, Luna-Rodriguez, & Jacobsen, 2012). Participants responded more quickly to a visual search task when the search target appeared in a location (or color) that was associated with the target stimulus in the preceding flanker task, and this filtering effect was more robust in a mostly incongruent condition. Given that the bias of the mostly congruent and mostly incongruent conditions of the flanker task was created by using a two-item set that would seemingly promote use of item-specific S–R associative learning (assuming similar processes are at play in flanker and Stroop tasks), their findings seem at odds with the AATC hypothesis. An important difference between the current experiments and that of Wendt et al. (2012) is that Wendt et al. used a task-switching paradigm (cf. Stroop task-switching paradigm of Fernandez-Duque & Knight, 2008). The role of the reliability of S–R associative learning in moderating top-down control might be minimized in contexts wherein the difficulty associated with maintaining and switching between two task sets may in and of itself trigger engagement of top-down control (possibly due to task-level conflict), even when associative learning can be utilized to achieve task goals on one of the tasks. This is an important question for future studies to address. Doing so would expand our understanding of the various factors that influence top-down control engagement, including their interactions.

Conclusion

Top-down control engagement is neither the default mode (Botvinick et al., 2001) nor a nonexistent strategy (Blais et al., 2007) in high-conflict contexts. Experiments 1a through 2b demonstrated that one factor that influences the engagement of top-down control for young adults is the degree to which item-specific S–R associative learning can be utilized to achieve task goals, consistent with the AATC hypothesis. I have suggested that engagement of top-down control might thus be viewed as a last resort, in that it comes on line when the environment alone does not guide responding most of the time (cf. Bargh & Chartrand, 1999). Experiment 3 demonstrated that older adults might be even more environmentally dependent than young adults, consistent with some prior research (Spieler et al., 2006), but it is also possible that older adults simply lack the ability to engage top-down control. In conclusion, the current findings suggest that experiencing conflict or expecting to experience conflict may have little effect on performance when S–R associations or other reliable sources of information (in the external environment) support performance.

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