

# Evidence for the Sparing of Reactive Cognitive Control With Age

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The dual mechanisms of control account posited two qualitatively different cognitive control mechanisms (Braver, Gray, & Burgess, 2007). Proactive control is a sustained and capacity-demanding mechanism that is used to prevent interference, whereas reactive control acts transiently, poststimulus onset, to resolve interference. Prior research has demonstrated age-related deficits in proactive control, including in conflict tasks. However, few studies have examined the putative sparing of reactive control with age, and the purpose of this study was to fill that gap. In Experiment 1, older adults, like young adults, showed less interference for mostly incongruent items than mostly congruent items in a picture-word Stroop task, and this pattern extended to novel, 50% congruent transfer items. In Experiment 2, flanker stimuli in one screen location (or color) were mostly congruent whereas flanker stimuli in a second location (or color) were mostly incongruent. Young and older adults demonstrated context-specific proportion congruence effects, showing less interference in the mostly incongruent as compared to mostly congruent context for the location cue but not the color cue. These findings provide converging evidence for the intact and flexible use of reactive control with age, and challenge the view that aging is associated with a general deficit in cognitive control.

*Keywords:* aging, cognitive control, troop, flanker, proportion congruence

Cognitive (i.e., executive) control refers to a set of processes that are used to coordinate various subprocesses (e.g., attention) in the service of goal-relevant action. These processes include shifting or switching between tasks, updating information in working memory, and interference control (e.g., inhibition of irrelevant responses) (Miyake et al., 2000). Interference control has long been thought to be susceptible to age-related decline, as captured in prominent theoretical accounts such as the inhibitory deficit theory (Hasher & Zacks, 1988; Zacks & Hasher, 1994). However, recent theorizing and empirical evidence identifying two qualitatively different control mechanisms prompt reconsideration of the ubiquity of age-related declines in interference control. In particular, the dual mechanisms of control account posited the existence of proactive and reactive control mechanisms (Braver, Gray, & Burgess, 2007). Proactive control is thought to act in a sustained (global) and preparatory fashion to prevent interference via the top-down biasing of attention in advance of the onset of stimuli (De Pisapia & Braver, 2006). This conceptualization coincides with classic conceptions of cognitive control as slow acting and effortful (e.g., Posner & Snyder, 1975; Shiffrin & Schneider, 1977). By contrast, reac-

tive control is thought to be less capacity demanding, in that it acts transiently, poststimulus onset, to resolve interference on an as-needed basis. This conceptualization is consistent with newer evidence of a fast-acting and “automatic” (Jacoby, Lindsay, & Hessels, 2003, p. 643) cognitive control mechanism, as evidenced by the stimulus-driven modulations of interference that have recently been observed in conflict tasks such as Stroop and flanker paradigms (e.g., context-specific control; Crump, Gong, & Milliken, 2006; Lehle & Hübner, 2008; item-specific control; Bugg, Jacoby, & Chanani, 2011; for reviews, see Bugg, 2012; Bugg & Crump, 2012).

According to the dual mechanisms of control account, aging is associated with impairment in proactive control. This view coincides with goal maintenance theory (see Braver & West, 2008, for review) and resource accounts that posit age-related decline in the capacity of working memory (Craig & Byrd, 1982). In addition, there are a number of empirical patterns indicating age-related declines in the top-down modulation of irrelevant information (for review, see Gazzaley & D’Esposito, 2007), and neuroimaging evidence showing age-related differences in sustained activation patterns (e.g., indicative of cue use; maintenance of goals during delays) in prefrontal cortex (Jimura & Braver, 2010; Paxton, Barch, Racine, & Braver, 2008). Braver et al. (2007) cited key findings from a continuous performance task (AX-CPT) as evidence of proactive control impairment (Braver et al., 2001; Braver, Satpute, Rush, Racine, & Barch, 2005). In the AX-CPT task, the goal was to respond only to AX trials (i.e., X trials that follow an A cue). Because AX trials occurred 70% of the time, presentation of an A served as an imperative cue to prepare proactively to respond to the subsequent target (X). Older adults made significantly more errors (had more misses) than young adults on AX trials, consistent with a deficit in proactive control. Also suggesting a deficit, older adults made significantly fewer errors on AY

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trials. On AY trials, intact proactive control is associated with *more* errors because the presentation of the A leads one to expect to respond when one should not.

The novel and largely untested prediction of the dual mechanisms of control account is that reactive control may be spared with age. Here, too, Braver et al. (2007) cited performance patterns from the AX-CPT task in support of this view. Older adults were significantly slower than young adults in responding to BX trials, which was interpreted as evidence for a reduction in proactive control—presentation of the B trial guided young but not older participants to prepare to inhibit responding to the subsequent X trial. The evidence for intact reactive control was that older adults did not make many errors on BX trials, which Braver et al. interpreted as indicating a sparing of “just-in-time” control processes that overrode older adults’ tendency to respond at the time of the onset of the X stimulus.

While the findings of Braver et al. (2001, 2005) provided preliminary support for the view that reactive control is spared with age, there were two major limitations. One is that their primary measure of reactive control, the error rate on BX trials, did not necessarily isolate the efficiency of reactive control. In other words, one might interpret BX errors in the same way BX reaction time (RT) was interpreted, as indicative of the efficiency of proactive control (i.e., extent to which cue-driven preparation processes were effective). A second limitation is the task-specificity of the evidence. It is important to examine whether older adults exhibit intact reactive control in other tasks for which interference control or inhibition is important, such as commonly employed conflict tasks (e.g., Stroop, flanker). The current study addressed these limitations by a) examining whether older adults are equally as likely as young adults to demonstrate reactive control of interference in picture-word Stroop (Experiment 1) and flanker (Experiment 2) tasks, when reactive control is assessed via relatively “pure” measures for which key performance patterns cannot be explained by proactive control or other theoretically relevant processes (e.g., associative learning).

### Dissociating Reactive From Proactive Control (and Associative Learning)

Manipulations of proportion congruence (i.e., the percentage of trials that are congruent relative to incongruent in a conflict task) have long been used to examine cognitive control (Logan & Zbrodoff, 1979). A critical factor modulating reliance on proactive versus reactive control processes is the level at which the proportion congruence manipulation is implemented (Bugg, 2012; Bugg & Crump, 2012). The traditional approach is to manipulate proportion congruence at the list level by presenting participants with lists of trials (i.e., blocks) that are mostly incongruent (MI) (i.e., the probability of interference is high [~75%]) or mostly congruent (MC) (i.e., the probability of interference is low [~25%]). Interference is significantly reduced in the MI as compared to MC list (i.e., the list-wide proportion congruence (LWPC) effect; Kane & Engle, 2003; Lindsay & Jacoby, 1994; Logan & Zbrodoff, 1979; Logan, Zbrodoff, & Williamson, 1984; Lowe & Mitterer, 1982; West & Baylis, 1998). The dominant account of the LWPC effect suggests use of proactive (top-down) control to globally bias attention away from the frequently distracting dimension in the MI list (e.g., words in the Stroop task; flanking stimuli in the flanker

task), thereby minimizing interference (Botvinick, Carter, Braver, Barch, & Cohen, 2001; Bugg, McDaniel, Scullin, & Braver, 2011; Bugg & Chanani, 2011; De Pisapia & Braver, 2006; Logan & Zbrodoff, 1979). In the MC list, participants expect the distractor to be congruent with the target and thus permit greater processing of it, which exacerbates interference on the occasional incongruent trial.

Two studies have investigated the LWPC effect in the color-word Stroop task for both young and older adult samples. A consistent pattern that emerged from the studies of West and Baylis (1998) and Mutter, Naylor, and Patterson (2005) was that a LWPC effect was found for both groups. Though this pattern appears to suggest that proactive control is not impaired for older adults, the LWPC manipulation used in these studies was confounded with item-specific proportion congruence (ISPC) (Blais & Bunge, 2010; Bugg, Jacoby, & Toth, 2008). It is therefore possible that reactive, item-specific mechanisms produced the effect. ISPC refers to the frequency with which particular items (e.g., words) are presented in a congruent relative to incongruent format. Jacoby et al. (2003) showed that manipulating proportion congruence at the item level also produced a proportion congruence effect (i.e., the ISPC effect). Reduced interference was found for MI items (e.g., the word *BLUE*) compared to MC items (e.g., the word *GREEN*).

The assertion that ISPC effects are driven by reactive mechanisms reflects two important features of the ISPC manipulation (Jacoby et al., 2003). One is that MC items and MI items are randomly intermixed such that the LWPC is 50%. As such, there is no basis off which to adopt a global control setting and apply it proactively, and moreover, proactive control would produce equivalent, not differential, interference for different items within the same list. Second, one cannot know in advance of a given trial whether the item will be MC or MI (because the sets are presented equally frequently). Only once the item is shown (i.e., poststimulus) can a reactive mechanism be triggered to respond optimally to the item. Two reactive mechanisms have been shown to contribute to ISPC effects. One is item-specific control, the modulation of word reading based on the degree to which an item has produced interference in the past (i.e., retrieval of a control setting that rapidly attenuates word processing upon presentation of a MI item) (Bugg, Jacoby, et al., 2011; Bugg & Hutchison, 2013). Item-specific control operates on the basis of learned stimulus–attention associations, that is, associations between particular stimuli (items) and the abstract attentional settings (e.g., minimize processing of distracting word) that have become bound to these stimuli (Bugg & Crump, 2012). A second is item-specific associative (i.e., contingency) learning, the prediction of responses on the basis of the irrelevant word dimension (Schmidt & Besner, 2008; cf. Melara & Algom, 2003). For example, if the word *BLUE* is an MI item and it appears 75% of the time in red ink, participants may show less interference in responding to this word because they can rapidly predict the response that is most frequently paired with it (e.g., say “red” whenever *BLUE* is presented), and not because they are quickly curtailing word reading via reactive, item-specific control. Contingency learning reflects the learning of specific stimulus–response associations not the learning of stimulus–attention associations.

Several studies have incorporated designs that examine the LWPC effect, independent of item-specific mechanisms, and pro-

vided evidence for the contribution of proactive control to the LWPC effect for young adults (Bugg & Chanani, 2011; Bugg, McDaniel et al., 2011; Hutchison, 2011). Only recently was such a design applied to examine whether older adults also employ proactive control. Bugg (in press) created MC and MI lists that were each comprised of two sets of items. One set (e.g., RED, BLUE, WHITE, and PURPLE) was used to establish the bias of the list and as such was 75% congruent when presented in the MC list and 25% congruent when presented in the MI list. A second set (e.g., PINK, GREEN, BLACK, and YELLOW) was 50% congruent. This set was exactly the same when embedded in the MC list or MI list (i.e., equal presentation frequency, equal item-specific proportion congruence level of 50%). Combining the 75% congruent and 50% congruent items yielded a list that was 67% congruent (MC) while combining the 25% congruent items and 50% congruent items yielded a list that was 33% congruent (MI). To examine whether young and older adults (aged 60–80) engaged proactive control (i.e., a global, top-down bias based on the frequency of conflict within a list), performance on the 50% congruent items was examined. A LWPC effect was found for young adults, who showed 40 ms less interference in the MI as compared to the MC list. By contrast, for older adults, the difference in interference between the two lists was a nonsignificant 3 ms. This suggests that older adults were impaired in proactively biasing attention so as to minimize interference when conflict was frequent, consistent with a number of accounts and prior findings including the dual mechanisms of control account (Craig & Byrd, 1982; Braver et al., 2007; Braver & West, 2008; Gazzaley & D'Esposito, 2007).

Lending support to the view that prior demonstrations of LWPC effects for older adults (Mutter et al., 2005; West & Baylis, 1998) may have reflected the contribution of item-specific mechanisms was a second finding from Bugg's (in press) study. A significant proportion congruence effect was found for older adults when comparing interference across lists by examining performance on the sets that had an item-specific bias. Indeed, the reduction in interference for the 25% congruent items in the MI list compared to the 75% congruent items in the MC list was significant, and of a very similar magnitude for older (61 ms) and young adults (67 ms). This finding suggests that older adults, like young adults, may show ISPC effects. A similar finding was obtained previously (Bugg et al., 2008); however, in that study it was highly likely that the item-specific proportion congruence effect stemmed from the contribution of item-specific associative learning, because the 25% congruent and 75% congruent sets were composed of only two items. As such, strong stimulus–response associations existed for congruent items in the MC set and incongruent items in the MI set, conditions that promote use of associative learning (Bugg & Hutchison, 2013, Experiment 3; Schmidt & Besner, 2008). In the study of Bugg (in press), however, the sets were composed of four items. As such, incongruent responses were never predictable, including in the MI set. With (larger) sets of this size, it has been shown that item-specific control contributes to ISPC effects. An important piece of evidence supporting this conclusion was the finding of selective transfer (Bugg & Hutchison, Experiment 3). In a four- but not a two-item set design, it was found that item-specific control settings transferred to novel 50% congruent items for which responses could not be predicted on the basis of item-specific associative learning but for which stimulus–attention as-

sociations were useful. Still, this evidence is indirect as transfer has not been examined for older adults, and more generally, a cleaner test is needed to examine age-related differences in reactive control in a context in which proactive control could not produce the critical patterns of performance.

## Experiment 1

The purpose of Experiment 1 was to examine the posited sparing of reactive control in older adults by examining whether an ISPC effect would be observed for older adults in a picture-word Stroop paradigm in which participants named the animal in the picture while ignoring the animal word, using a design that has been shown to produce item-specific control for young adults (Bugg, Jacoby, et al., 2011, Experiment 2; see Bugg & Hutchison, 2013, Experiments 1 and 2 for a replication with the color-word Stroop task). As described in detail elsewhere (Bugg, Jacoby, et al., 2011; Bugg, 2012), the critical feature of this design is that it unconfounds contingency from ISPC by assigning items to MC and MI sets based on the relevant dimension rather than the irrelevant dimension. It is important to note that this means the “signal” of ISPC, here the to-be-named picture, perfectly predicts the correct response 100% of the time, for all trial types (MC-congruent, MC-incongruent, MI-congruent, MI-incongruent). This differs from the typical design in which the irrelevant (to-be-ignored) word is the signal of proportion congruency, which leads to a confound such that particular trial types are high contingency (MC-congruent, MI-incongruent) and others are low contingency (MC-incongruent, MI-congruent), leaving open the possibility that any ISPC effect that emerges from the design is due to the differential contingencies (Jacoby et al., 2003; Schmidt & Besner, 2008).

Another important advantage of the current design is that it permitted a direct test of transfer, that is, whether an ISPC effect would be observed for novel, 50% congruent items that participants did not have experience with during the first two blocks of the task. Transfer represents an important piece of evidence countering associative (contingency) learning accounts of ISPC effects, and Bugg, Jacoby, et al. (2011, Experiment 2) demonstrated transfer of item-specific control for young adults in the picture-word Stroop task. However, it is unknown whether older adults exhibit transfer. If an item-specific proportion congruence effect were to be found for older adults on transfer trials, it would suggest that upon presentation of a new exemplar from one of the trained animal categories, participants retrieved and applied the control settings that were used to respond to the animal categories during the training trials (e.g., if an MI animal, retrieval of the control setting for attenuating word processing). This would imply a flexible use of reactive control with age.

Based on the dual mechanisms of control account, it was predicted that older adults would show evidence of reactive control, just like the young adults from Bugg, Jacoby, et al. (2011, Experiment 2), who served as the comparison group in the present study. This would be evidenced as a significant ISPC effect for older adults that would mirror the pattern for young adults (in Bugg, Jacoby, et al.), with the effect reflecting an asymmetrical influence of the ISPC manipulation on the incongruent trials (a pattern which is theoretically important in ruling out frequency-based and contingency-accounts as detailed by Bugg, Jacoby, et al.). Note

that the two groups might, however, differ in the time course of the effects with young adults, for example, showing evidence of ISPC effects earlier (e.g., in the initial block or two) than older adults.

The two groups could conceivably differ on transfer trials as well. If older adults demonstrated a similar pattern of transfer as the young adults, including a selective effect on incongruent trials, this would provide strong support for the view that reactive (item-specific) control, and not simply associative learning, is spared with age. Older adults may, however, be less flexible in their use of reactive control, in that the control settings may be more bound to prior experience (specific exemplars) and less likely to generalize. If so, older adults may demonstrate an ISPC effect on the training trials but may not show the effect on the transfer trials. While this pattern would not rule out that reactive control produced the ISPC effect on the training trials, an additional analysis was conducted on the training trials to further examine any possible contributions of associative (contingency) learning to the ISPC effect. The analysis (which I describe in more detail in the Results section) was devised for this same purpose in a color-word Stroop study (Bugg & Hutchison, 2013, Experiments 1 & 2) that replicated the findings of Bugg, Jacoby, et al. (2011, Experiment 2). In the current study, this analysis was applied not only to the older adult data, but was also applied (for the first time) to the young adult data from Bugg, Jacoby, et al. (2011).

## Method

**Participants.** Sixteen young adults ( $M_{\text{age}} = 19.20$ ,  $SD = 1.04$ ; 63% female) from Washington University in St. Louis participated for course credit. These young adults' data were reported in a prior study (Bugg, Jacoby, et al., 2011, Experiment 2). For purposes of examining age differences in the current study, I collected data from 25 community dwelling older adults ( $M_{\text{age}} = 74.68$ ,  $SD = 6.32$ ; 68% female). The older adults were from the Washington University Older Adult Subject Pool and participated for monetary compensation. All participants were native English speakers and reported normal or corrected-to-normal vision and color vision.

Vocabulary test scores were equivalent for young ( $M = 35.00$ ,  $SD = 2.03$ ) and older adults ( $M = 34.95$ ,  $SD = 4.99$ ),  $t < 1$ . Older adults reported 15.46 ( $SD = 2.27$ ) years of education, and reported being in good health ( $M = 4.1$ ,  $SD = .87$  on a scale of 1 (*poor*) to 5 (*excellent*), respectively).<sup>1</sup>

**Design and materials.** The design and materials were identical to those used by Bugg, Jacoby, et al. (2011, Experiment 2). Briefly, the picture-word Stroop stimuli comprised a picture of one of four animals (bird, cat, dog, or fish) paired with one of the same animal names (BIRD, CAT, DOG, or FISH). For the training trials, there were four exemplars of each animal presented equally often. The animal pictures used during the training trials were separated into two sets, with each set of items presented equally frequently during the task. Animal pictures from one set (e.g., birds and cats) were presented as MC items and animal pictures from the second set (e.g., dogs and fish) were presented as MI items (see Table 1 for the presentation frequency of items from MC and MI sets). For example, pictures of birds and cats were 75% congruent while pictures of dogs and fish were 25% congruent. Assignment of animals to sets was counterbalanced across participants. The corresponding words from the MC set (BIRD and CAT) were 56%

Table 1  
*Frequencies of Stimulus Presentation for Mostly Congruent and Mostly Incongruent Items for the Training and Transfer Trials in Experiment 1*

	Picture			
	Mostly congruent		Mostly incongruent	
	bird <sub>1,2,3,4</sub>	cat <sub>1,2,3,4</sub>	dog <sub>1,2,3,4</sub>	fish <sub>1,2,3,4</sub>
Word				
BIRD	36	4	12	12
CAT	4	36	12	12
DOG	4	4	12	12
FISH	4	4	12	12
	bird <sub>5,6,7</sub>	cat <sub>5,6,7</sub>	dog <sub>5,6,7</sub>	fish <sub>5,6,7</sub>
Word				
BIRD	9	3	3	3
CAT	3	9	3	3
DOG	3	3	9	3
FISH	3	3	3	9

*Note.* The upper table represents the number of training trials in each block and the lower table represents the number of transfer trials (presented in third block only). There were fewer training trials in the third block; however, the proportion congruency of the presented items was maintained. The shaded grey cells indicate congruent trials.

congruent while the words from the MI set (DOG and FISH) were 38% congruent.

For the training trials, three unique exemplars of each animal were presented equally often. Exemplars from the animal categories that were MC during training and those from the animal categories that were MI during training were both presented in a 50% congruent format, with an equal number of presentations of exemplars from both sets (see Table 1).

**Procedure.** The procedure was identical to Bugg, Jacoby, et al. (2011, Experiment 2). Instructions indicated that the goal was to name aloud the animal in the picture as quickly as possible while maintaining a high level of accuracy. They were instructed to use general (e.g., bird) not specific animal names (e.g., robin). After a brief set of practice trials, participants completed three blocks of test trials. Transfer trials appeared only in the third block, intermixed with training trials. Stimuli were presented on-screen until a voice response was detected. An experimenter coded the participant's response and the next stimulus appeared 1 s later. Trials on which the voice key was tripped by extraneous noise or imperceptible speech were coded as scratch trials and excluded from analyses. Reaction time (ms) and error rate were recorded.

## Results

One older adult's data were excluded because he or she had error rates between 21 and 35% ( $>3 SD$  beyond the group's mean) for the incongruent trial types. A second, older adult's data were excluded because the participant refused to call one of the cat pictures "cat" and instead called it "dog," which could have influenced his or her learning of the proportion congruency of cats versus dogs.

<sup>1</sup> Five older adults did not complete the vocabulary test.

The alpha level was set at .05. Partial eta squared ( $\eta_p^2$ ) is reported as the measure of effect size. Bugg, Jacoby, et al. (2011) trimmed .003% of the RTs from the young adults' RT distribution. Consequently, we trimmed the upper .003% of all RTs within the older adults' RT distribution, which resulted in RTs slower than 3,590 ms being excluded (cf. Mayr, 2001).<sup>2</sup> Incorrect trials were also excluded from the RT analysis. The mean error rate was <3% for both young and older adults and was not analyzed further.

**Training trials.** The mean RTs are presented in Table 2. Mean RTs were submitted to a 2 (Age)  $\times$  2 (Item Specific Proportion Congruence)  $\times$  3 (Block)  $\times$  2 (Trial Type) mixed ANOVA with age as the between-subjects factor. There was a main effect of age,  $F(1, 37) = 35.01$ ,  $MSE = 208234$ ,  $\eta_p^2 = .486$ , due to older adults ( $M = 918$ ,  $SE = 27$ ) being slower than young adults ( $M = 664$ ,  $SE = 33$ ). There was also a main effect of proportion congruence,  $F(1, 37) = 5.71$ ,  $MSE = 6938$ ,  $\eta_p^2 = .134$ , indicating faster responses for MI items ( $M = 782$ ,  $SE = 22$ ) as compared to MC items ( $M = 800$ ,  $SE = 22$ ) and a main effect of trial type,  $F(1, 37) = 222.06$ ,  $MSE = 9186$ ,  $\eta_p^2 = .857$ , indicating faster responses on congruent ( $M = 724$ ,  $SE = 19$ ) than incongruent ( $M = 858$ ,  $SE = 25$ ) trials. An age  $\times$  trial type interaction indicated that interference (Incongruent RT – Congruent RT) was more pronounced for older ( $M = 177$ ) than young adults ( $M = 92$ ),  $F(1, 37) = 22.13$ ,  $MSE = 9186$ ,  $\eta_p^2 = .374$ .

In addition, there was a proportion congruence  $\times$  trial type interaction, indicative of the ISPC effect,  $F(1, 37) = 26.28$ ,  $MSE = 2618$ ,  $\eta_p^2 = .415$ . Less interference was observed for MI items ( $M = 110$ ) than MC items ( $M = 159$ ). Importantly, the age  $\times$  proportion congruence  $\times$  trial type interaction was not significant,  $F(1, 37) = 1.13$ ,  $p = .294$ , which suggested comparable ISPC effects for young and older adults. Still, it was theoretically important to determine if each group showed a statistically significant ISPC effect. As Bugg, Jacoby, et al. (2011) reported, younger adults did ( $F(1, 15) = 14.97$ ,  $MSE = 407.85$ ,  $\eta_p^2 = .500$ ). Critically, for older adults, the proportion congruence  $\times$  trial type interaction was also significant, revealing an ISPC effect,  $F(1, 22) = 17.13$ ,  $MSE = 1190$ ,  $\eta_p^2 = .438$ . Less interference was found for MI items than MC items for both age groups ( $M_s = 73$  vs. 111, respectively, for young adults;  $M_s = 147$

vs. 206, respectively, for older adults), and the effect sizes were comparable for young and older adults. Also similar for the two age groups was the nature of the interaction. For young adults, the interaction stemmed from a significant, 36 ms speeding of RTs for MI-incongruent items relative to MC-incongruent items; RTs on congruent trials were similar for the MI and MC items (Bugg et al., 2011). For older adults, a significant 51 ms speeding of RTs was observed for MI-incongruent items compared to MC-incongruent items,  $t(22) = 2.82$ , while RTs were similar for MI-congruent and MC-congruent trials,  $t < 1$ .

Of note, the block  $\times$  age  $\times$  proportion congruence  $\times$  trial type interaction approached significance,  $F(2, 74) = 2.81$ ,  $MSE = 1369$ ,  $p = .067$ . Given the potential theoretical significance of this effect, it was decomposed. Follow-up three-way ANOVAs for each block reflected that the age  $\times$  proportion congruence  $\times$  trial type interaction was significant for Block 1,  $F(1, 37) = 5.98$ ,  $MSE = 1594$ ,  $\eta_p^2 = .139$ , but was not significant for Blocks 2 or 3,  $F_s < 1$ . Quite interestingly, the ISPC effect was significant for older ( $F(1, 22) = 17.30$ ,  $MSE = 2285$ ,  $\eta_p^2 = .440$ ) but not young adults,  $F(1, 15) = 2.59$ ,  $p = .128$ , in Block 1 (83 ms reduction in interference for MI as compared to MC items for older adults vs. 19 ms reduction for young adults) but was of a similar size in subsequent blocks (56 ms and 41 ms in Block 2 and 41 ms and 57 ms in Block 3 for older and young adults, respectively).

**Content analysis of errors during training trials.** In the Method section, it was noted that the design yielded words that were 56% congruent (44% incongruent) in the MC condition and 38% congruent (62% incongruent) in the MI condition. It might therefore be argued that the learning of word–response contingencies affected performance (Schmidt, 2013). To evaluate this claim, Bugg and Hutchison (2013) devised an analysis that assesses the content of participant's responses on error trials. Note that Bugg, Jacoby, et al. (2011) did not report this analysis for the young adults in their study. The analyses below, based on 187 error trials for young and 235 error trials for older adults, represent the first report of these theoretically important findings for both age groups.

The content analysis evaluated two predictions based on a contingency account that posits learning of word–response associations: a) participants should respond with animal names that were more frequently paired with a particular word than animal names that were less frequently paired with a particular word, and b) participants should be more likely to respond with the congruent animal name for words from the MC condition (wherein the congruent animal name is the single high contingency response), but this pattern should not be evident for the MI condition (wherein the congruent animal name is not the single, most frequently paired response option). Reported in Table 3 is the average probability with which a participant produced a particular errant response alternative (“bird,” “cat,” “dog,” or “fish”) collapsed across words as a function of how frequently a particular response alternative was paired with a given word during training trials. These data are presented separately for items in the mostly congruent and mostly incongruent sets. With respect to the first

<sup>2</sup> Bugg, Jacoby, and Chanani (2011) used a box trim excluding trials faster than 200 ms or greater than 3,000 ms. One might therefore reason that the trimming for the older adults should not have been restricted to the upper .003%. However, only one trial in the older adult distribution was faster than 200 ms. Removing this trial did not change any of the results.

Table 2  
Mean Reaction Times (SEs) for Mostly Congruent and Mostly Incongruent Items for Training and Transfer Trials in Experiment 1

Condition	Items	Trial type	Young	Old
Training	Mostly congruent	Congruent	617 (16)	826 (29)
		Incongruent	728 (20)	1032 (40)
		Interference	111	206
	Mostly incongruent	Congruent	620 (18)	834 (29)
		Incongruent	693 (16)	981 (41)
		Interference	73	147
Transfer	Mostly congruent	Congruent	624 (17)	841 (28)
		Incongruent	718 (19)	1041 (45)
		Interference	94	200
	Mostly incongruent	Congruent	631 (21)	860 (38)
		Incongruent	693 (21)	1002 (43)
		Interference	62	142

Note. Interference refers to  $Incongruent_{RT} - Congruent_{RT}$

Table 3

*Average Probability With Which Particular Response Alternatives Were Produced on Error Trials in Experiment 1*

Age group	# of Presentations	Mostly congruent		# of Presentations	Mostly incongruent	
		Picture	BIRD		Picture	DOG
Young	36 (congruent)	bird	0.59	4	bird	0.15
	4	cat	0.14	4	cat	0.07
	12	dog	0.17	12 (congruent)	dog	0.68
	12	fish	0.10	12	fish	0.10
Older	36 (congruent)	bird	0.52	4	bird	0.14
	4	cat	0.17	4	cat	0.16
	12	dog	0.21	12 (congruent)	dog	0.52
	12	fish	0.10	12	fish	0.17

*Note.* The words BIRD and DOG are used for illustrative purposes only. The probabilities presented in the table reflect the average probability collapsed across all words (BIRD, CAT, DOG, FISH) separately for the mostly congruent and mostly incongruent items.

prediction, it was not the case that the responses that were paired more frequently with particular words (i.e., those associated with a presentation frequency of 12) were consistently produced more frequently than responses that were paired less frequently with particular words (i.e., those associated with a presentation frequency of 4). For example, for the MC set, the response that was paired with the word four times was produced more frequently (.14) by young adults than the response that was paired with one of the words that was presented 12 times (.10). The probability of producing the other word that was presented 12 times was .17; although greater than .14, as a contingency account would expect, it is certainly not three times greater as should be the case if contingency learning were influencing performance. For older adults in the MC set, the same pattern was evident (.17 for response paired four times vs. .10 for one of the two responses that were paired 12 times, and .21 for the other). Similarly within the MI set, it is clear that the probability of responding with a particular word does not align closely with presentation frequency. For example, for older adults, the probabilities of producing the two responses that were paired with the word on four occasions were .14 and .16, while the probability of producing the response that was paired with the word 12 times was .17. These data do not support the contingency learning account.

To test the second prediction, I compared the probabilities of producing the response that was congruent with the word across the MC and MI conditions. For both young and older adults, it is quite clear that for both conditions, contrary to a contingency account, the most frequently produced errant response was the congruent response (Young<sub>MC</sub> = .59; Young<sub>MI</sub> = .68; Old<sub>MC</sub> = .52; Old<sub>MI</sub> = .52). While the contingency account anticipated this pattern for the MC condition, given that congruent responses were highly contingent responses, it did not anticipate this pattern for the MI condition, which should not lead to use of the word to predict the congruent response.

**Transfer trials.** Mean RTs appear in Table 2. Mean RTs were submitted to a 2 (Age) × 2 (Item Specific Proportion Congruence) × 2 (Trial Type) mixed ANOVA with age as the between-subjects factor. As was found for the training trials, there was a main effect of age,  $F(1, 37) = 33.13$ ,  $MSE = 82799$ ,  $\eta_p^2 = .472$ , a main effect of trial type,  $F(1, 37) = 94.15$ ,  $MSE = 6201$ ,  $\eta_p^2 = .718$ , and an age × trial type interaction,  $F(1, 37) = 13.22$ ,  $MSE = 6201$ ,  $\eta_p^2 = .263$ . Most importantly, there was a proportion congruence × trial type interaction,  $F(1, 37) = 8.80$ ,

$MSE = 2179$ ,  $\eta_p^2 = .192$ , and the age × proportion congruence × trial type interaction was not significant,  $F < 1$ . As Bugg, Jacoby, et al. (2011) reported, young adults demonstrated a significant ISPC effect ( $F(1, 15) = 10.24$ ,  $MSE = 408$ ,  $\eta_p^2 = .406$ ), for which the effect size and nature of the interaction (asymmetrical effect of ISPC on the incongruent trials) was comparable to the training trials. A 2 × 2 ANOVA indicated that the ISPC effect was also found for older adults on the transfer trials,  $F(1, 22) = 5.68$ ,  $MSE = 3387$ ,  $\eta_p^2 = .205$ , although the effect size was about half of the size of the effect on the training trials. Comparable to young adults, however, the nature of the interaction mirrored that observed for the training trials. RTs were significantly faster on incongruent trials for the MI condition than the MC condition,  $t(22) = 2.33$ , while congruent trial RTs were equivalent across the two conditions,  $t(22) = 1.06$ ,  $p = .299$ .

## Discussion

The findings of the current study provided strong evidence to support the view that reactive control is spared with age. Older adults demonstrated ISPC effects during the training trials that were significant and of a comparable size to those of young adults. Moreover, the ISPC pattern mirrored closely that found previously for young adults (Bugg, Jacoby, et al., 2011), specifically that the effect was driven by a selective influence of the ISPC manipulation on incongruent trials, with RTs being significantly faster for MI-incongruent items than MC-incongruent items. There are several bases from which one can conclude that this pattern reflects item-specific control and not associative (contingency) learning (or other frequency-dependent processes). First, the design unconfounded contingency and ISPC by using the relevant dimension (picture) as the ISPC signal, which made the signal 100% predictive of responses in all cells, and ISPC effects were still found. Second, although the ISPC signal—the relevant dimension—was no longer confounded with PC, the design did yield words that were still somewhat predictive of responses (in MC set, words were 56% congruent, while in MI set, words were 38% congruent), thereby leaving open the possibility that associative (contingency) learning played a role in the difference in interference that was found for MC versus MI items (ISPC effect; Schmidt, 2013). However, contrary to this possibility, the content analysis of errors on training trials revealed little to no evidence in support of the

predictions of the contingency account (cf. Bugg & Hutchison, 2013). Third, the nature of the ISPC pattern itself countered the typical, contingency-driven ISPC pattern of there being a selective difference on congruent trials (Bugg, Jacoby, et al., 2011, Experiment 3) or a difference on both congruent and incongruent trials (e.g., Jacoby et al., 2003; Schmidt & Besner, 2008). In addition, the ISPC pattern countered the view that older (or young) adults are simply sensitive to the frequency with which particular stimuli are presented, as frequency-based views (e.g., instance theory; Logan, 1988) also anticipate a difference on congruent trials (given that MC-congruent trials are presented more frequently than MC-incongruent trials).

The current finding of no age difference in the ISPC effect conceptually replicates the study of Bugg (in press) in which older adults demonstrated an ISPC effect for 75% and 25% congruent items that were used to create an overall LWPC bias. The current study additionally found that older adults, like young adults, demonstrated transfer of the ISPC effect to novel 50% congruent items. This is a novel and exciting result. It suggests that older adults, like young adults, retrieved and applied the (abstract) control setting previously associated with a category of animals during the training trials upon presentation of the novel transfer trials. Indeed, the ISPC pattern on the transfer trials closely approximated the pattern from the training trials for both groups. One notable difference between the groups was that the transfer trial ISPC effect was about half the size of the training trial ISPC effect for older adults, whereas young adults' transfer effect was more similar in size to their training effects. This may be due to older adults being less flexible in their use of reactive control, possibly because in the face of a related but novel ISPC signal (i.e., a picture of a new animal from the mostly incongruent animal category), the relatively automatic retrieval of the abstract attentional setting was muted (cf. Mullet et al., in press, for a similar finding in prospective memory).

A final pattern that merits note concerns the trend for the ISPC effect on training trials to differ for young and older adults depending on block. In the first block, older adults demonstrated a larger ISPC effect than young adults who showed similar levels of interference for the MC and MI items. In subsequent blocks, the two groups showed similarly sized ISPC effects. This is yet another pattern that is difficult to reconcile with a view of the ISPC effect that suggests it reflects learning of simple, stimulus–response associations. Surely young adults should learn such associations more quickly than older adults. One interesting possibility is that upon beginning a Stroop task, young adults may engage proactive control. Older adults may not, because of impairments in this control mechanism (Bugg, in press). If young adults engage proactive control, one would expect there to be no difference between the MC and MI sets, as proactive control should treat all items similarly (i.e., filtering words) and doing so should lead to less learning about the relationship between particular items and particular proportion congruency levels. The absence of an ISPC effect for young adults in the first block is consistent with this possibility.

## Experiment 2

The purpose of Experiment 2 was to seek converging evidence for the sparing of reactive control with age by examining whether older and young adults show similar or differing patterns of

context-specific proportion congruence (CSPC) effects in a flanker task.

Manipulating proportion congruence at the context level is another approach to obtaining measures of interference that selectively reflect reactive control. In the CSPC paradigm, contextual cues are differentially predictive of the probability of interference (Crump et al., 2006; see also Corballis & Gratton, 2003). In a seminal study, Crump et al. (2006) found that Stroop interference was significantly reduced in the MI context (e.g., an upper location on screen), wherein there was typically a mismatch between words and colors, as compared to the MC context (e.g., a lower location on screen), wherein the word and color typically matched. This effect has been conceptually replicated in the flanker paradigm (e.g., Lehle & Hübner, 2008; Vietze & Wendt, 2009).

As in the ISPC paradigm, a proactive control mechanism is unable to explain the differential operation of control trial-to-trial because it has no basis off which to operate (i.e., the lists are 50% congruent, and the finding of different levels of interference for different locations suggest a single global control setting is not operative); participants do not know whether the probe appears in the MI or MC location until it is presented. Thus, any control adjustments must take place poststimulus onset in a reactive fashion. The term *context-specific control* has been used to refer to the modulation of distractor processing at the time of stimulus onset depending on the distractor's utility in the context in which the stimulus appears (Crump et al., 2006). Similar to item-specific control, underlying context-specific control is the learning of the association between particular contextual cues (e.g., locations) and the optimal attentional settings that have been deployed during past experiences with stimuli in each location. A MI location becomes, for example, associated with an abstract attentional setting that minimizes attention to the flankers.

Importantly, CSPC effects cannot be explained by simple associative learning because all responses are equally likely in the presence of each contextual cue. In other words, the contextual cues cannot be used to predict the correct response (i.e., simple stimulus [cue]–response learning is ineffective); however, and critically, the contextual cues do predict the probability of interference (i.e., stimulus [cue]–proportion congruency learning is beneficial). Use of this information about the relationship between particular contextual cues and levels of proportion congruence (i.e., the upper location has a high likelihood of interference while the lower location has a low likelihood of interference) permits control to be achieved via activation of an abstract attentional setting that is appropriate for a given contextual cue (e.g., reducing attention to the distractors in the MI location).

That the CSPC effect reflects a reactive control process and not a more complex learning process that is sensitive to the frequency with which particular contextual cue/distractor compounds and responses co-occur is evidenced by the following findings. First, the effect transfers to novel, frequency unbiased stimuli that are 50% congruent in both contexts (i.e., interference is reduced when novel probe stimuli are presented in the MI relative to the MC location, with the proportion congruence of each location determined by a separate set of stimuli) (Crump & Milliken, 2009). Second, CSPC effects are consistently obtained when location is the contextual cue (e.g., Corballis & Gratton, 2003; Crump et al., 2006; Crump & Milliken, 2009; Crump, Vaquero, & Milliken, 2008; Vietze & Wendt, 2009; Wendt, Kluwe, & Vietze, 2008), but

mixed findings exist for identity-based cues such as shape and color (Crump et al., 2006; Crump et al., 2008; Lehle & Hübner, 2008; Vietze & Wendt, 2009). For example, Crump et al. (2006) contrasted location-based and shape-based cues and found a CSPC effect for only the location cue. As Crump et al. noted, if the complex learning of contextual cue/distractor compounds and responses underlies the CSPC effect, it is unclear why such a process would not contribute to performance when identity-based cues are utilized.

There are no studies that have examined whether there are age-related differences in the CSPC effect. The current study did so by examining CSPC effects for young and older adults for a location-based contextual cue and a color-based contextual cue. It was expected that a CSPC effect would be observed for the location cue but not the color cue (e.g., Crump et al., 2006), and that, similar to Experiment 1, these patterns would be evident for both young and older adults.

## Method

**Participants.** Forty-eight young adults from Washington University in St. Louis participated for course credit or monetary compensation, and 33 community dwelling older adults from the Washington University Older Adult Subject Pool participated for monetary compensation. All participants reported normal or corrected-to-normal vision and color vision, and were right-handed.<sup>3</sup>

Twenty-five young ( $M_{\text{age}} = 19.20$ ,  $SD = 1.04$ ; 65% female) and 17 older adults ( $M_{\text{age}} = 70.00$ ,  $SD = 5.93$ ; 65% female) completed the location-cue version of the task. Vocabulary test scores were similar for young ( $M = 33.92$ ,  $SD = 2.38$ ) and older adults ( $M = 34.41$ ,  $SD = 2.92$ ),  $t < 1$ . Twenty-three young ( $M_{\text{age}} = 19.22$ ,  $SD = 1.17$ ) and 16 older adults ( $M_{\text{age}} = 71.25$ ,  $SD = 5.11$ ) completed the color-cue version of the task. Vocabulary test scores were lower for young ( $M = 34.09$ ,  $SD = 1.86$ ) than older adults ( $M = 37.5$ ,  $SD = 1.57$ ),  $t(33) = 5.43$ ,  $p < .001$ .<sup>4</sup>

Because participants who completed the color-cue version of the task were recruited subsequent to completion of the location-cue version, it was important to examine whether the participants in each version were approximately equivalent on potentially important characteristics. The young adults in the two versions did not differ on age or vocabulary test scores,  $t_s < 1$ . The older adults in the two versions did not differ in age,  $t < 1$ , or years of education,  $t(30) = 1.24$ ,  $p = .226$ . However, while the older adults who performed the color-cue version had higher vocabulary scores than the older adults who performed the location-cue version,  $t(27) = 3.33$ ,  $p < .01$ , those who performed the location-cue version reported better health than those who performed the color-cue version, ( $M = 4.1$  vs.  $M = 3.5$  on a scale of 1 (poor) to 5 (excellent), respectively),  $t(30) = 2.01$ ,  $p = .053$ .

**Design and materials.** A 2 (Age: Young vs. Older)  $\times$  2 (Cue Type: Location vs. Color)  $\times$  2 (Context-Specific Proportion Congruence: MC vs. MI)  $\times$  2 (Trial Type: Congruent vs. Incongruent) mixed design was used. Age and cue type were between-subjects factors and context-specific proportion congruence and trial type were within-subjects factors.

A four choice version of the arrow-based flanker task (cf. Eriksen & Eriksen, 1974) was used. Arrows pointed left, right, up, or down. On congruent trials, all arrows in the stimulus array

Table 4  
Frequencies of Stimulus Presentation for the Mostly Congruent and Mostly Incongruent Locations (or Colors) in Experiment 2

Context	Flankers	Target (Correct response)			
		<	>	^	v
Mostly congruent	<	27	3	3	3
	>	3	27	3	3
	^	3	3	27	3
	v	3	3	3	27
Mostly incongruent	<	9	9	9	9
	>	9	9	9	9
	^	9	9	9	9
	v	9	9	9	9

Note. The shaded grey cells indicate congruent trials.

pointed in the same direction (e.g., <<<<<<<<). There were four congruent stimulus arrays. On incongruent trials, the central arrow pointed in a direction that was incompatible with the flanker arrows (e.g., <<<<><<<<). All combinations of distracter and target identity were used to create 12 incongruent stimulus arrays. Stimulus arrays were accompanied by a central fixation cross.

In the location-cue version, flanker stimuli were rendered in black. Half of the stimuli appeared in a location above fixation and the other half appeared in a location below fixation. One of the two locations was designated MC and the other MI, with this assignment counterbalanced across participants. In the color-cue version, flanker stimuli were rendered in red or blue, and half of the stimuli appeared in red and half appeared in blue. Both red and blue stimuli appeared in a single (upper) location. One of the two colors was designated MC and the other MI, with this assignment counterbalanced across participants.

Table 4 depicts the frequency of stimulus presentation for congruent and incongruent trials in the MC and MI contexts. For the MC location/color, 75% of stimuli were congruent and 25% were incongruent. For the MI location/color, 75% of stimuli were incongruent and 25% were congruent. Stimuli were randomly intermixed during presentation. Each location/color cue was equally associated with all four responses, and stimuli were 50% congruent at the block level.

**Procedure.** After participants provided informed consent, they completed a demographics questionnaire. They were then seated at a computer and instructed that stimuli would be presented one at a time on screen. Stimuli were presented via E-prime software. Participants were told to respond to the direction a central arrow was pointing by pressing the response key that corresponded to that direction (e.g., press the left key for a left-facing central arrow, the up key for an up-facing central arrow, etc.) using the index finger of their right hand. They were told to respond as quickly as possible without sacrificing accuracy. Participants responded via a number pad on a standard keyboard, with the “4” used for a left response, the “6” for a right response, the “2” for a down response, and the “8” for an up response. Participants were instructed to use the “5” key as a home key, to which they

<sup>3</sup> Additionally, six young and eleven older adults participated who were left-handed; these participants’ data were excluded.

<sup>4</sup> Four older adults did not complete the vocabulary test.

would return and rest their index finger after making each response. Following 12 practice trials, participants performed three blocks of 96 trials. On each trial, the stimulus was presented and remained on screen until a response was made. A 1,000 ms response to stimulus interval (RSI) followed. The screen was blank during this interval. A brief break was provided between blocks. Reaction time (RT) (ms) and error rate were recorded. Following the flanker task, participants completed the Shipley vocabulary test, and were debriefed and thanked.

**Results**

The alpha level was set at .05. Partial eta squared ( $\eta_p^2$ ) is reported as the measure of effect size. For the RT analysis, the upper 1% of all RTs within each age group’s RT distribution was trimmed (for young, RTs  $\geq 1,326$  in location-cue version and  $\geq 1,029$  in color-cue version; for old, RTs  $\geq 3,305$  in location-cue version and  $\geq 2,257$  in color-cue version) (cf. Mayr, 2001). One older adult in the location-cue version had RTs that were  $>3 SD$  from the group mean. This participant’s data were excluded.

Incorrect trials were excluded from the RT analysis. Error rate was extremely low ( $<1\%$ ) for young and older adults and was not further analyzed. One exception was one older adult in the location-cue version whose error rates were between 20 and 25% for the incongruent trial types ( $>3 SD$  beyond the group’s mean) and whose data were therefore excluded.

Mean RTs are presented in Table 5. Mean RTs were submitted to a 2 (Age)  $\times$  2 (Cue Type)  $\times$  2 (Context Specific Proportion Congruence)  $\times$  3 (Block)  $\times$  2 (Trial Type) mixed ANOVA with age and cue type as the between-subjects factors. Older adults ( $M = 969, SE = 19$ ) were significantly slower than young adults ( $M = 568, SE = 15$ ),  $F(1, 75) = 274.47, MSE = 132433, \eta_p^2 = .785$ . A main effect of trial type indicated a significant congruency effect,  $F(1, 75) = 375.39, MSE = 4244, \eta_p^2 = .833$ , whereby RT was slower on incongruent ( $M = 811, SE = 13$ ) as compared to congruent trials ( $M = 727, SE = 12$ ). The age  $\times$  trial type interaction was not significant,  $F < 1$ . A main effect of cue type indicated that RTs were faster in the color cue condition ( $M = 704, SE = 17$ ) than the location cue condition ( $M = 833, SE = 17$ ),  $F(2, 150) = 28.34, MSE = 132433, \eta_p^2 = .274$ . A main effect of block

was qualified by a block  $\times$  age interaction,  $F(2, 150) = 35.36, MSE = 6026, \eta_p^2 = .320$ , indicating that the speeding of RTs across blocks was more pronounced for older ( $M_s = 1034, 949, \text{ and } 925$ , respectively, from Block 1 to Block 3) than young adults ( $M_s = 572, 566, \text{ and } 565$ , respectively, from Block 1 to Block 3), and a block  $\times$  cue type interaction. The speeding of RTs across blocks was more prominent in the location cue condition (71 ms speeding from Block 1 to Block 3) than the color cue condition (44 ms speeding from Block 1 to Block 3). Most importantly, significant two-way interactions between trial type and cue type, and between proportion congruence and trial type, were qualified by a significant, three-way interaction between cue type, proportion congruence and trial type,  $F(1, 75) = 6.15, MSE = 1620, \eta_p^2 = .076$ , which I decompose below. No other effects were significant, including the block  $\times$  proportion congruence  $\times$  trial type interaction or any higher-order interactions,  $F_s \leq 2.26, p_s > .10$ .

**Color cue.** For the color cue, the proportion congruence  $\times$  trial type interaction was not significant,  $F < 1$ , nor was the proportion congruence  $\times$  trial type  $\times$  age interaction,  $F < 1$ . Interference was equivalent for stimuli in the MC color and MI color for both young ( $M_s = 58$  ms and 57 ms of interference, respectively) and older adults ( $M_s = 65$  ms and 58 ms of interference, respectively).

**Location cue.** By contrast, for the location cue, a significant proportion congruence  $\times$  trial type interaction was observed,  $F(1, 38) = 14.27, MSE = 627, \eta_p^2 = .273$ , indicative of the CSPC effect. The congruency effect (i.e., interference) was significantly reduced for stimuli in the MI ( $M = 94$ ) as compared to MC ( $M = 125$ ) location. The three-way age  $\times$  proportion congruence  $\times$  trial type interaction was not significant,  $F = 1.36, p = .252$ . However, before accepting this as evidence for a context-specific proportion congruence effect for both young and older adults, the effect was examined separately for each age group.

Two 2 (Context Specific Proportion Congruence)  $\times$  2 (Trial Type) within-subjects ANOVAs were conducted. The proportion congruence  $\times$  trial type interaction was significant for young adults,  $F(1, 24) = 8.26, MSE = 345, \eta_p^2 = .256$ , and older adults,  $F(1, 14) = 5.52, MSE = 1108, \eta_p^2 = .283$ . The second analysis oriented toward examining the pattern underlying the CSPC effect. Notably, both young and older adults demonstrated a similar CSPC pattern. Incongruent trial RTs were significantly faster in the MI location as compared to the MC location for young adults (14 ms benefit),  $t(24) = 2.39$ , and a similar trend was observed for older adults (29 ms benefit),  $t(14) = 1.95, p = .071$ . There was no significant difference between RTs on congruent trials in the MC and MI locations for young,  $t(24) = 1.01, p = .324$  or older adults ( $t < 1$ ).

**Discussion**

A novel experiment was conducted examining reactive control via a CSPC manipulation in young and older adults. The primary finding was that young and older adults independently demonstrated significant and equivalently sized ( $\eta_p^2 = .256$  vs.  $.283$  for young vs. older adults) CSPC effects, showing less flanker interference when stimuli were presented in the MI location relative to the MC location. The time-course of this effect did not differ for young and older adults, as indicated by the lack of an interaction of the effect with block. For both young and older adults, the

Table 5  
Mean Reaction Times (SEs) for Mostly Congruent and Mostly Incongruent Contexts for the Color and Location Cue Conditions in Experiment 2

Cue	Items	Trial type	Young	Old
Color	Mostly congruent	Congruent	477 (20)	870 (25)
		Incongruent	535 (24)	935 (29)
		Interference	58	65
Color	Mostly incongruent	Congruent	478 (22)	873 (26)
		Incongruent	535 (24)	931 (28)
		Interference	57	58
Location	Mostly congruent	Congruent	572 (20)	977 (25)
		Incongruent	691 (23)	1106 (30)
		Interference	119	129
Location	Mostly incongruent	Congruent	579 (21)	987 (27)
		Incongruent	677 (23)	1077 (29)
		Interference	98	90

Note. Interference refers to  $Incongruent_{RT} - Congruent_{RT}$ .

reduction in interference in the MI location was driven by a speeding of response times on incongruent trials in the MI as compared to MC location, indicative of a more efficient resolution of flanker-based interference in the MI location. Neither group demonstrated a difference in congruent trial RT between the MI and MC location. Collectively, these findings converge on the conclusion that older adults are not impaired, relative to young adults, in engaging context-specific cognitive control.

The CSPC effect found in the current study cannot be explained by simple associative learning because all responses were equally likely in the MI and MC locations. Before concluding that there is age equivalence in context-specific control, however, it is important to address a second, alternative account. One might argue that a more complex learning process that is sensitive to the frequency with which particular contextual cue/distractor compounds and responses co-occur could account for the CSPC and, possibly, the absence of age differences (e.g., Hommel, 1998; Logan, 1988). While the transfer findings of Crump and Milliken (2009) deem this unlikely, as noted in the introduction, two key findings from the current study also challenge this account. The first is that the CSPC pattern for young and older adults was driven by a selective effect of proportion congruence on the incongruent trials. Young adults were significantly faster in responding to incongruent trials in the MI as compared to the MC location, and this difference approached significance for older adults. If a complex learning process was responsible for producing the CSPC effect, it also should have produced an advantage on congruent trials in the MC location. Participants had three times as many exposures to each type of congruent trial in the MC as compared to the MI location, yet neither young nor older adults demonstrated a speeding of RTs for congruent trials in the MC location ( $ps > .32$ ).

To make this point concrete, assume for example a complex learning representation of the form “go with the majority of arrows in the lower location” and “go against the majority of arrows in the upper location,” or “several arrows pointing left at the bottom of the screen require a left response” and “several arrows pointing left at the top of the screen require a \_\_\_\_\_ response,” representations, which include a response component. With respect to the absence of a difference in RTs for congruent trials across locations, why would there not be a benefit associated with “going with the majority” or “responding left when several arrows point left”? Similarly, how would “going against the majority” produce a benefit to performance on incongruent trials in the MI case, given the 4-choice nature of the flanker task and equal distribution of responses for each location/distractor compound on incongruent trials (see Table 4)? Said differently, there is no clear response choice to fill in the blank in the case of “several arrows pointing left at the top of the screen require a \_\_\_\_\_ response.”

In contrast to these representations, the representation that is assumed to support context-specific control is a stimulus (cue)-attention representation, such as “pay less attention to flankers” when stimuli are presented in the lower location. It is interesting that the more pronounced influence of the CSPC manipulation on incongruent trials mirrored the pattern obtained in Experiment 1 and in prior studies that have isolated reactive control (the activation of stimulus-attention representations) from the influences of associative learning in the ISPC paradigm (Bugg, Jacoby, et al., 2011; Bugg & Hutchison, 2013; but

see Crump & Milliken, 2009, for what appears to be a non-asymmetrical pattern although comparisons were not performed). Moreover, the primary extant computational models of reactive control posit that adjustments in control as a function of item- and context-specific proportion congruence are conflict-triggered (Blais, Robidoux, Risko, & Besner, 2007; Verguts & Notebaert, 2008), which fits well with the present finding of a selective effect on incongruent trials, for which conflict is present.

A second key finding that poses a challenge to a complex learning account is the cue  $\times$  proportion congruency  $\times$  trial type interaction. That is, the CSPC effect was obtained for the location cue but not the color cue for both young and older adults. As noted in the introduction, others have questioned why a complex learning process would not produce a CSPC effect when identity based cues such as color or shape are utilized instead of location cues (Crump et al., 2006). That is, why would the learning of color cue/distractor compound–response associations not be possible? An explanation has thus far not been provided in the literature. By contrast, some have pointed to the relative accessibility of location versus color cues as an important determinant of a cue’s effectiveness in triggering the rapid instantiation of control settings purported to support reactive, context-specific control (Crump et al., 2006; Lehle & Hübner, 2008). The rapid retrieval of control settings post-stimulus onset seemingly demands that the cue that signals which setting to retrieve is detected very quickly and attended, given that any corresponding adjustments (i.e., to flanker processing) must take place within a narrow time window (several 100 ms). There is evidence that location but not color cues are detected relatively automatically (Logan, 1998) and given priority during encoding (Mayr, 1996).

## General Discussion

The dual mechanisms of control account posited that reactive control was spared with age, but minimal, indirect evidence was available to support this prediction, and that evidence was limited to a select task (AX-CPT) (Braver et al., 2007). The current findings provided direct and converging evidence for intact reactive control with age from two distinct paradigms, one that assessed ISPC effects in a picture-word Stroop task and one that assessed CSPC effects in an arrow version of the flanker task. For both paradigms, alternative accounts were tested and little to no evidence was found to support the view that associative learning processes were responsible for the effects.<sup>5</sup> Viewed alongside extant theories and empirical evidence for a deficit in proactive cognitive control with age (e.g., Braver et al., 2007; Bugg, in press; Gazzaley & D’Esposito, 2007), the novel patterns revealed herein challenge the long-

<sup>5</sup> The assertion is not that contingency learning never contributes to paradigms in which proportion congruence is manipulated. Indeed, in my own work, I have acknowledged and provided evidence for the contribution of contingency learning processes to particular LWPC and ISPC designs (Bugg, 2013, Experiment 1b and 2a; Bugg, Jacoby, and Toth, 2008, Experiment 1; Bugg et al., 2011, Experiment 3; Bugg & Hutchison, 2013, Experiment 3). One could not confidently assert that aging is associated with spared reactive control were a design of this nature employed in the present study.

held notion in the aging literature of ubiquitous age-related deficits in cognitive control. As such, the current findings echo the general sentiment of Verhaeghen (2011), who recently assailed the assumption of a general decline in cognitive control with age. He found that age-related deficits were observed for tasks that required divided attention but were not apparent for local task-shifting costs or selective attention tasks (e.g., Stroop, flanker).

Verhaeghen's (2011) conclusions regarding cognitive control, however, could easily have been interpreted as support for the sparing of associative learning processes with age. As Melara and Algom (2003) and Dishon-Berkovits and Algom (2000) have noted, commonly it is the case that distractors (e.g., words in Stroop or flanker arrows in flanker) carry information about responses or congruency in selective attention tasks such as Stroop, thereby permitting reactive processes to be used to achieve optimal performance. Verhaeghen's meta-analysis did not differentiate between selective attention measures that could reflect associative learning processes and those that reflect control. The present findings of intact reactive cognitive control (see also suggestive evidence from Bugg, *in press*) in a variety of selective-attention tasks (Stroop; flanker) provide clear and unambiguous evidence for the sparing of reactive control with age. Only with this evidence in hand can it be concluded that selective attention tasks may (often) be immune to age-related decline because the type of control (i.e., reactive control) that is used for resolving interference in such tasks is one that may (often) be immune to age-related decline.

Perhaps the most intriguing theoretical question stimulated by the current findings is that of why reactive control is spared with age. One might presume the brain regions used to support reactive control differ from those used to support proactive control, and differential aging of these regions could account for the patterns. For example, contextual control might rely more heavily on the posterior attention system (e.g., parietal cortex) than the more strategically oriented anterior attention system (Posner & Petersen, 1990). Indeed, a recent fMRI study found that the neural substrate of context-specific control, described by the authors as an associative triggering of a top-down control state for a particular location, lies in the posterior parietal cortex (King, Korb, & Egner, 2012). There is evidence suggesting an anterior-to-posterior gradient in age-related deterioration of the brain (e.g., Head et al., 2004; West, 1996; cf. Hartley, 1993), raising the possibility that systems supporting contextual control may age more slowly than those supporting proactive control. This may similarly be true for item-specific control mechanisms but no studies to date have identified the neural correlates of item-specific control independent of associative learning. Alternatively or in addition, there may be an age-related shift toward reactive activation of brain regions associated with cognitive control, such as lateral prefrontal cortex, and away from sustained activation (Braver, Paxton, Locke, & Barch, 2009).

Another possibility is that reactive control may not be susceptible to decline with age because the processes supporting item-specific and context-specific control appear to be implicit in nature. Crump et al. (2006) showed that young participants were not explicitly aware of the relationship between certain contextual cues and proportion congruence, which suggests that contextual control adjustments may be rather implicit. By contrast, proactive

processes, such as preparing attention to avoid processing an irrelevant stimulus dimension or preparing to withhold a response when given a B cue in the AX-CPT, may involve more conscious strategies. That older adults are spared in engaging an implicit process would coincide with previous findings in implicit learning paradigms such as spatial contextual cueing (Howard, Howard, Dennis, Yankovich, & Vaidya, 2004), and implicit memory paradigms such as perceptual priming (see Rybash, 1996, for review). It is also plausible that the sparing of the fast-acting and flexible reactive control mechanism may best be thought of as a specific case of the general pattern of invariance of automatic influences on behavior with age (e.g., Balota, Black, & Cheney, 1992; Jennings & Jacoby, 1993).

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