Context-specific attentional sampling: Intentional control as pre-requisite for contextual control.

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Abstract

Recent work suggests that environmental cues associated with previous attentional control settings can rapidly and involuntarily adjust attentional priorities. The current study tests predictions from adaptive-learning and memory-based theories of contextual control about the role of intentions for setting attentional priorities. To extend the empirical boundaries of contextual control phenomena, and to determine whether theoretical principles of contextual control are generalizable we used a novel bi-dimensional stimulus sampling task. Subjects viewed briefly presented arrays of letters and colors presented above or below fixation, and identified specific stimuli according to a dimensional (letter or color) and positional cue. Location was predictive of the cued dimension, but not the position or identity. In contrast to previous findings, contextual control failed to develop through automatic, adaptive-learning processes. Instead, previous experience with intentionally changing attentional sampling priorities between different contexts was required for contextual control to develop.

Keywords: Attention, Memory, Cognitive Control, Conflict Adaptation, Context-specific, Task Relevance

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Introduction

Attentional control refers to processes that alter priorities for selecting relevant versus irrelevant information during task performance. Although attentional priorities are widely understood to be set in an effortful intentional fashion (Posner & Snyder, 1975), they may also be set in a cue-driven fashion. For example, research across paradigms in attention suggests that contextual cues can trigger the automatic retrieval and reinstatement of attentional control settings previously used in those contexts in the past (for reviews, see Bugg & Crump, 2012; Cosman & Vecera, 2013; Egner, 2008). The present experiments contribute to this body of work by showing new evidence of location-based contextual control over priorities for sampling from briefly presented bi-dimensional (e.g., letters and colors), multi-element displays. More important, across experiments we find that contextual control over sampling in this procedure depends on an intentional learning phase where subjects explicitly deploy different sampling strategies in different location contexts. These findings contrast with several existing demonstrations of contextual control that do not appear to depend on intentional processing, and they are also not well explained by accounts of contextual control that posit a role for learning processes that automatically adapt to the statistics of the environment. To set the stage for the present work, we briefly review the range of evidence for contextual control, what is known about the roles of awareness and intention in acquiring contextual control, and how these issues are treated among major theories of contextual control.

Demonstrations of contextual control over attentional priorities have been observed in procedures tapping different aspects of attention. For example, repeating the configuration of distractors in visual search facilitates target detection (Chun, 2000; Chun & Jiang, 1998). Stroop interference reflecting priorities for processing color versus word information is modulated by contextual cues (location, shape, font) associated with different proportions of congruent and incongruent items (Crump & Milliken, 2009; Crump, Gong, & Milliken, 2006; Crump, Vaquero, & Milliken, 2008). Flanker interference reflecting priorities for selecting a target in space from nearby distractors is also modulated by contexts associated with different proportions of congruent and incongruent items (Corballis & Gratton, 2003; Crump, 2016; King, Korb, & Egner, 2012). Similarly, task-switching costs reflecting task-specific attentional priorities can be modulated by contextual cues associated with specific tasks (Mayr & Bryck, 2007), and different proportions of switch and repeat trials (Crump & Logan, 2010). Attention capture by salient feature singletons (Cosman & Vecera, 2013; see also, Le Pelley, Vadillo, & Luque, 2013) can also be modulated by context cues (e.g., visual scenes) associated with differing attentional sets. Related findings showing cue-driven control over the setting of attentional priorities can be found in negative priming (Milliken, Thomson, Bleile, MacLellan, & Giammarco, 2012), priming of pop-out (Thomson & Milliken, 2013), and masked-priming (Heinemann, Kunde, & Kiesel, 2009; Panadero, Castellanos, & Tudela, 2015; Reuss, Desender, Kiesel, & Kunde, 2014). The present experiments borrow techniques from demonstrations of contextual control over congruency effects in classic selective attention procedures like Stroop or flanker; so, we discuss those demonstrations more closely as a venue for reviewing the roles of awareness and intention in contextual control.

Interference tasks like Stroop (1935) and flanker (B. A. Eriksen & Eriksen, 1974) require subjects to identify a target dimension while ignoring a distractor dimension. For example, in the Stroop task (for a review, see MacLeod, 1991) subjects identify the ink-color of a written color word, and performance is typically worse when the distracting word is incongruent (e.g., the word RED is printed in blue) than congruent (e.g., the word RED is printed in red) with the required response. The size of this difference, termed the congruency effect, is taken as an index of selective attention: larger differences show failures to prevent distractors from influencing performance, and smaller differences show success in preventing distractors from influencing performance. Proportion congruent manipulations modulate the size of congruency effects, and are a common tool for measuring control processes that set attentional priorities for target and distractor processing (for a review, see Bugg & Crump, 2012). Proportion congruent manipulations vary the relative proportion of congruent and incongruent items in a task. Generally, congruency effects are larger in blocks of trials that have a higher than lower proportion of congruent items (Logan & Zbrodoff, 1979).

Contextual control over congruency effects has been shown using context-specific proportion congruent manipulations. For example, Crump et al. (2006) presented Stroop items in a randomized intermixed fashion in one of two locations that were associated with a high or low proportion of congruent items. In this design, subjects were unable to predict whether an upcoming trial would be congruent or incongruent, or whether an item would appear in a location that was high or low proportion congruent. Nevertheless, larger congruency effects were found for the items in the high than low proportion congruent locations. This finding is consistent with contextual control over attentional sets, whereby rapid, online processing of location cues associated with different levels of proportion congruent trigger adjustments to priorities for filtering color and word dimensions of a current item. The CSPC effect has been reported several times in Stroop (Bugg, Jacoby, & Toth, 2008; Crump & Milliken, 2009; Crump et al., 2008), and flanker tasks (Corballis & Gratton, 2003; Wendt & Luna-Rodriguez, 2009; Wendt, Kluwe, & Vietze, 2008).

The interpretation that CSPC effects reflect automatic contextual control depends on a subject's state of awareness and possible intention to set attentional priorities by context. We use awareness to refer to explicit knowledge of the proportion congruent manipulation, the source of conflict, or the presence of contextual cues. We use intention to refer to a deliberate route for setting attentional priorities. Subjects could become aware of the CSPC manipulation, that attentional requirements vary by context, and then deliberately set attentional priorities separately for each context. Intentional control could prepare two different strategies in advance, or rapidly shift attentional priorities in response to the presentation of a context cue. Either way, the CSPC effect would not provide clear evidence for an automatic cue-driven influence over attentional priorities. Additionally, subjects could be aware of the CSPC manipulation, but decide not to intentionally assign different attentional priorities between contexts. In this case, intentional control would not explain CSPC effects, although awareness could play a role in learning about predictive cues. Subjects could also be unaware of the CSPC manipulation, and presumably for that reason would not intentionally set attentional priorities in a context-specific fashion that would produce consistent CSPC effects. Here, CSPC effects would be more consistent with an automatic, cue-driven influence over the setting of attentional priorities.

Awareness of the CSPC manipulation has been assessed by post-experimental questionnaires. All of the studies measuring awareness showed that subjects could not accurately report the relative proportions of congruent items between contexts (Crump & Logan, 2010; Crump et al., 2006; Gough, Garcia, Torres-Quesada, & Milliken, 2014; King et al., 2012; Sarmiento, Shore, Milliken, & Sanabria, 2012). A few studies have also manipulated awareness. Crump et al. (2008) for example, tested whether awareness of the CSPC manipulation would be sufficient for producing contextual control using shape cues, which were previously found to be an ineffective cue for observing CSPC effects (Crump et al., 2006). Subjects were informed about the CSPC manipulation, encouraged to use shape-specific attentional control strategies, and signed a statement acknowledging they understood the instructions. CSPC effects for shape cues were not observed, and subjects were unable to accurately complete the post-experiment awareness questionnaire. Awareness of conflict between the relevant and irrelevant dimensions has also been assessed as a pre-requisite for CSPC effects. For example, CSPC effects can be produced in masked-prime procedures where subjects are not aware of the source of response conflict (Heinemann et al., 2009; Panadero et al., 2015; Reuss et al., 2014; but see, Schouppe, Ferrerre, Van Opstal, Braem, & Notebaert, 2014). Reuss et al. (2014) embedded the contextual cue within the masked prime and found CSPC effects even when the prime was below a perceptible threshold. Taken together, these studies suggest that awareness of the CSPC manipulation, source of response conflict, and in one case the presence of a contextual cue, are not prerequisites for contextual control; they also suggest that CSPC effects are not driven by intentional means.

Process theories of CSPC effects and contextual control phenomena generally do not invoke awareness or intention as pre-requisites for acquiring or displaying cue-driven control after learning. We review two general classes of theories termed adaptive learning and memory-based accounts.

Adaptive learning theories explain contextual control in terms of automatic learning processes sensitive to the statistics of the environment, and have a long history in attention (Moray & Fitter, 1973) and associative learning (Mackintosh, 1975) theory. Generally speaking, adaptive learning processes update attentional priorities in response to errors, such that future errors are minimized (Kruschke, 1992, 2001, 2003, 2010). Similar approaches using response conflict signals (Botvinick, Braver, Barch, Carter, & Cohen, 2001) have modeled item-specific proportion congruent effects (Blais, Harris, Guerrero, & Bunge, 2012), and could account for CSPC effects if items in each context were represented individually. Verguts and Notebaert (2008, 2009) also showed that a Hebbian learning rule could further control how conflict signals update attentional priorities. More generally, experienced conflict, actual errors, and error estimates all represent learning signals by which performance could potentially be optimized Verguts and Notebaert (2008). According to these models, the prerequisites for acquiring contextual control include the presence of a learning signal, and the presence of statistical regularities among environment cues that can direct optimization. Awareness of environmental regularities, or intentional control of attentional prioritization are not required for contextual control.

Memory-based theories explain contextual control by cue-driven retrieval and reinstatement of prior attentional priorities (Crump, 2016; Crump & Milliken, 2009; Crump et al., 2006, 2008). Memory traces store the perceptual details of specific experiences and the attentional priorities for information processing assigned during those experiences. In this way, cues in the present moment can retrieve similar instances from memory and reinstate the attentional priorities used in the past to update attentional priorities in the present. Memory-driven theories can be flexible with respect to the roles of awareness and intention. The critical assumption of the memory account is that subjects possess memory traces that code different attentional priorities for different contexts. The theory suggests that context-specific attentional priorities could be obtained through various means, including adaptive learning, or intentional control at the level of items or contexts. First, adaptive learning processes could work in concert with memory and provide the mechanism for changing attentional priorities in a context-specific fashion. Second, memory processes could produce contextual control through generalization of attentional priorities for specific items that vary between contexts. For example, subjects may intentionally modify attentional priorities for specific items to maximize speed and accuracy, and item-specific priorities associated to and retrieved by context cues could generalize to other items appearing in those contexts. Finally, memory processes could rely on initial awareness of context-specific differences in attentional requirements, and subsequent intentional control to assign different attentional priorities between contexts. In this way, memory would be populated with instances that code context-specific attentional priorities, which could then be retrieved in an automatic cue-driven fashion.

Taking stock, research into contextual control has generated numerous empirical demonstrations and some process theories with generalizable principles for explaining how cues acquire the ability to adjust attentional priorities during performance. A broad aim of the present experiments was to evaluate the generalizability of predictions from adaptive-learning and memory-based theories, especially with respect to intentional control. Our approach was to examine the acquisition of contextual control in a novel task that required subjects to prioritize sampling from one of two dimensions (letters or colors) in briefly presented multi-element displays. The use of a novel task had the dual benefits of assessing whether theoretical predictions are paradigm-specific or paradigm-general, as well as identifying new empirical boundaries for contextual control phenomena. The major finding across experiments is that contextual control in our task depends on intentional control. That is, previous experience with intentionally changing attentional sampling priorities between different contexts is a pre-requisite for contextual control over sampling from briefly presented displays.

Experiment 1

Our task was similar to Sperling's (1960) partial report paradigm where complex visual displays are presented followed by instructions indicating target selection criterion. We used bi-dimensional displays containing letter and colors, which allow for independent, selective processing (Bundesen, Kyllingsbæk, & Larsen, 2003; Kyllingsbæk & Bundesen, 2007). Each display contained a row of four different letters inside four uniquely colored squares. Displays were briefly presented (300 ms) followed by a task cue to report the identity of the letter or color that appeared in one of the squares (see Figure 1).

Borrowing from the location-based CSPC manipulation, our displays appeared in one of two locations above or below the fixation, and location was predictive of the identification task (color vs. letter), but not the position or identity of the items in each display. Specifically, one location involved 75% color and 25% letter identification trials, and the other location involved 75% letter and 25% color identification trials, so the location predicted the current task with 75% validity. We use the term valid to refer to trials where each identification task appeared in its likely location (75%), and the term invalid to refer to trials where each identification task appeared in its unlikely location (25%).

Thus, we created experimental conditions that have produced contextual control over congruency effects in Stroop and flanker. We assumed these conditions would also produce location-based control over attentional priorities for sampling from distinct dimensions in briefly presented visual displays. Specifically, we expected that identification accuracy would be higher for both letter and color targets when displayed in their respective valid than invalid locations. We did not inform subjects that location was predictive of the identification task, and we expected that subjects would not become aware of the manipulation. From the perspective of adaptive learning theories of contextual control, we assumed that attentional priorities would shift automatically in response to errors or conflict.

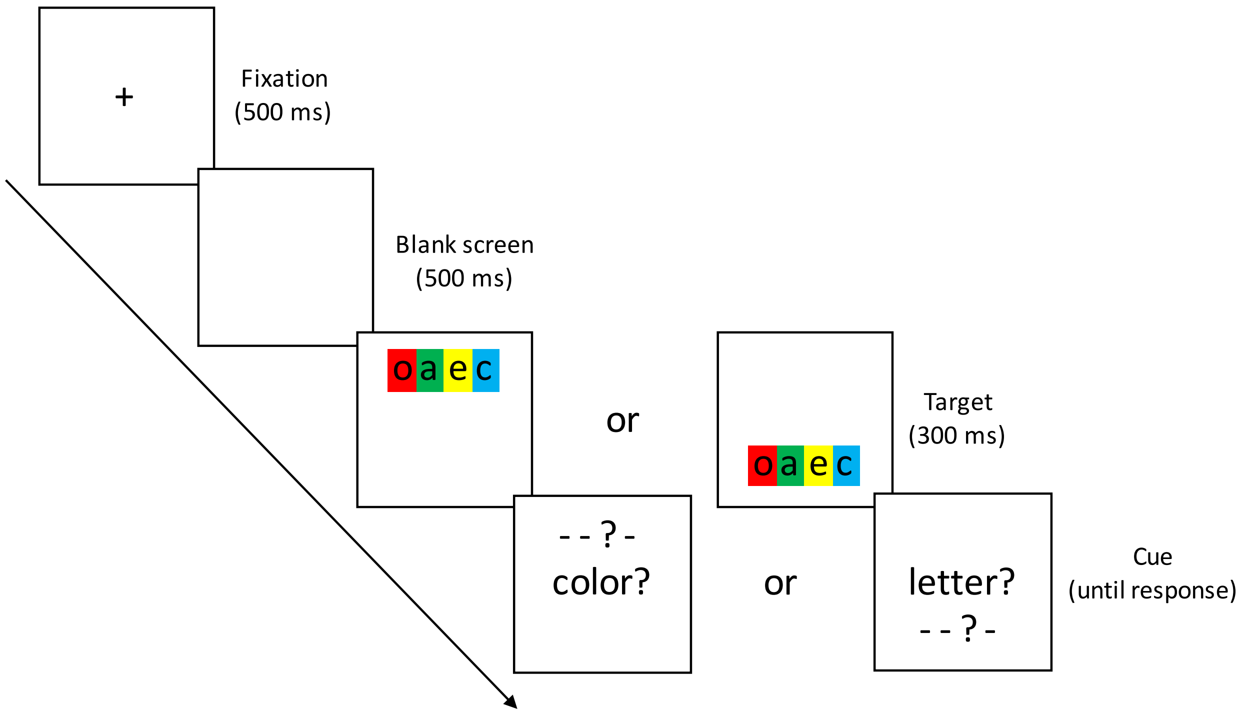

Figure 1. Note that the target could appear above or below the fixation. The identity cue ("Color?" or "Letter?") always appeared in the center of the screen while the position cue ("- - ? -") always appeared in the same location as the target. Participants were instructed to report either the letter or color in the cued position.

Methods

Subjects. All subjects were Brooklyn College undergraduate students (approximately ages 18-22) who participated for course credit. Twenty subjects completed Experiment 1 and all were included in the analysis.

Apparatus & Stimuli. All experiments were programmed using LiveCode 7.0. The target stimuli consisted of four lower-case letters (o, e, c, and a) superimposed on four colored squares (red, green, blue, and yellow). The relative positions of letters and colors on each trial were randomly chosen from all possible letter/color permutations. The background was black and stimuli were presented either above or below the fixation on a dark gray rectangle.

The keyboard was labeled to indicate the four letters and four color responses required. The keys A, S, D, and F were relabeled to A, O, E, and C respectively; and, the keys H, J, K, and L were relabeled as red, blue, green, and yellow, respectively.

Design. Experiment 1 used a 2x2 within-subjects design with cue validity (75% vs. 25%) and task (color identification vs. letter identification) as factors. There were 480 trials in Experiment 1. One location (randomly assigned as above or below the fixation) consisted of 75% color identification trials (160 trials) and 25% letter identification trials (80 trials) while the other location consisted of 75% letter identification trials and 25% color identification trials. The trial sequence was randomized and presented in an intermixed fashion for each subject.

Procedure. Each subject read a brief overview about the stimuli they would be presented and the types of responses required before signing a consent form. Subjects were instructed to remember the locations of both the colors and letters. Immediately following the target stimulus, a cue would indicate the to-be-identified target, which could be a letter or a color, located in any of the four positions.

Each trial began with a white fixation-cross presented in the center of the screen for 500 ms followed by a blank screen for 500 ms. Next, the target stimulus containing the four letters and four colors appeared for 300 ms followed immediately by the instructions for which stimulus to identify. The dimension of the to-be-identified stimulus was indicated by the words “Letter?” or “Color?” presented in the center of the screen and its location was indicated by three dashes and a question mark (i.e., “- - ? -”) presented in the same location as the target stimulus (see Figure 1). For example, “Letter?” and “? - - -” would indicate the letter located in the first position. No accuracy feedback was given following a response and the next trial began automatically. A mandatory 30-second break was given every 120 trials.

Table 1
Mean correct color and letter identification response latencies, standard errors, and accuracy rates for all experiments.

	Task		Training Phase		Mixed Phase			
			100%		75%		25%	
			M	SE	M	SE	M	SE
Exp. 1								
	Color	ACC	-	-	64.56	3.58	63.32	3.63
		RT	-	-	1611	70	1606	68
	Letter	ACC	-	-	61.84	3.56	62.17	3.35
		RT	-	-	1824	83	1858	90
Exp. 2								
	Color	ACC	75.02	3.55	64.81	4.36	63.36	4.71
		RT	1152	47	1510	59	1556	67
	Letter	ACC	77.11	3.23	58.31	3.4	59.09	3.88
		RT	1309	61	1707	80	1711	83
Exp. 3								
	Color	ACC	79.83	3.08	67.59	4.65	56.62	4.91
		RT	1318	61	1595	58	1687	62
	Letter	ACC	81.99	2.54	65.56	3.55	56.62	5.13
		RT	1560	96	1751	64	1858	87
Exp. 4								
Trained Context	Color	ACC	67.71	4	58.4	4.34	45	4.91
		RT	1519	80	1524	52	1596	52
	Letter	ACC	77.81	4.14	56.04	4.52	48.12	5.39
		RT	1686	90	1625	43	1620	74
Reversed Context	Color	ACC	-	-	56.53	4.93	51.88	4.96
		RT	-	-	1489	31	1526	61
	Letter	ACC	-	-	52.01	4.46	47.08	5.17
		RT	-	-	1607	36	1616	60

Note: RT = Reaction Time (ms); ACC = Accuracy (%); M = Mean; SE = Standard Error; 100%\75%\25% = Cue Validity.

Results

Overall identification accuracy was fairly low with an average accuracy of 63%, though subjects were well above chance (25%). Given the low accuracy scores, a response time analysis was inappropriate as nearly 40% of trials would have been removed from the analysis resulting in insufficient cell sizes. Furthermore, accuracy was well below ceiling levels of performance and therefore, would be sensitive to improvements in performance. Mean RTs and accuracy scores for all experiments are displayed in Table 1.

Mean accuracy scores for each subject in each condition were submitted to a repeated-measures ANOVA with cue validity (75% vs. 25%) and task (color identification vs. letter identification) as factors. Mean accuracy rates collapsed across subjects are presented in Figure 2.

Both main effects for cue validity, $F(1, 19) = 0.21$, $MSE = 19.70$, $p = .654$, $\hat{\eta}^2_p = .011$, and task $F(1, 19) = 0.49$, $MSE = 152.59$, $p = .492$, $\hat{\eta}^2_p = .025$, were non-significant. Additionally, the two-way interaction between cue validity and task was also non-significant, $F(1, 19) = 0.44$, $MSE = 28.19$, $p = .517$, $\hat{\eta}^2_p = .022$. Accuracy was not significantly better for targets presented in their valid versus invalid locations.

Discussion

Experiment 1 failed to demonstrate context-specific control over priorities for sampling from color vs. letter dimensions in briefly presented displays. Specifically, identification performance did not vary as a function of location cue validity. The absence of contextual control occurred despite the significant amount of errors made in all locations. So, although there was an opportunity for adaptive learning processes to modify attentional priorities based on error signals (in this case, the subjective appraisals of performance), those processes did not appear to influence performance. We cannot rule out whether or not additional practice was necessary for contextual control to develop; however, it clearly did not develop with amounts of practice sufficient to produce contextual control in related procedures.

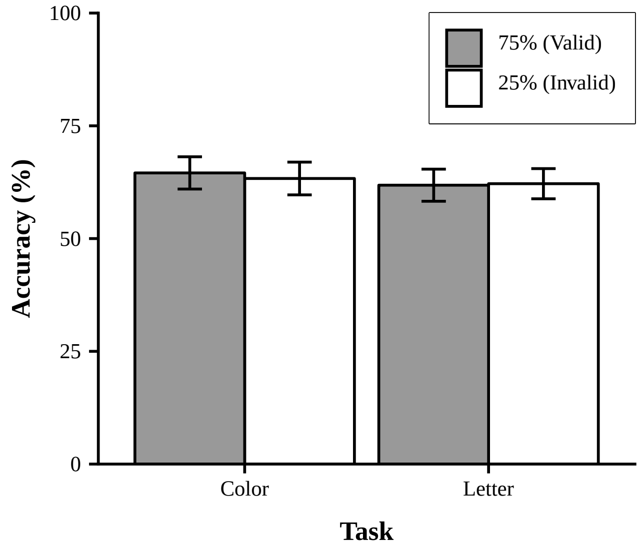

Figure 2. Accuracy scores (%) for color and letter identification trials as a function of location cue validity.

One possibility is that subjects did not attempt to intentionally change attentional priorities for sampling from color and letter dimensions between location contexts, and instead adopted a "sample-everything" strategy. This strategy would not prioritize one dimension over another, but would instead involve attempting to register as many details about both dimensions as possible. If subjects were employing such an experiment-wide indiscriminate sampling strategy, then their memory record would not be populated with instances preserving different attentional priorities between contexts. Experiment 2 was designed to populate the memory record with traces where attentional priorities were modified between contexts.

Experiment 2

The memory-driven account proposes that attentional processing details are stored in individual memory traces. Contextual control is then the result of the cue-driven retrieval and reinstatement of prior attentional priorities (Crump, 2016; Crump & Milliken, 2009; Crump et al., 2006, 2008). One interpretation of the absence of contextual control in experiment one was the possibility that subjects were adopting the very same "sample

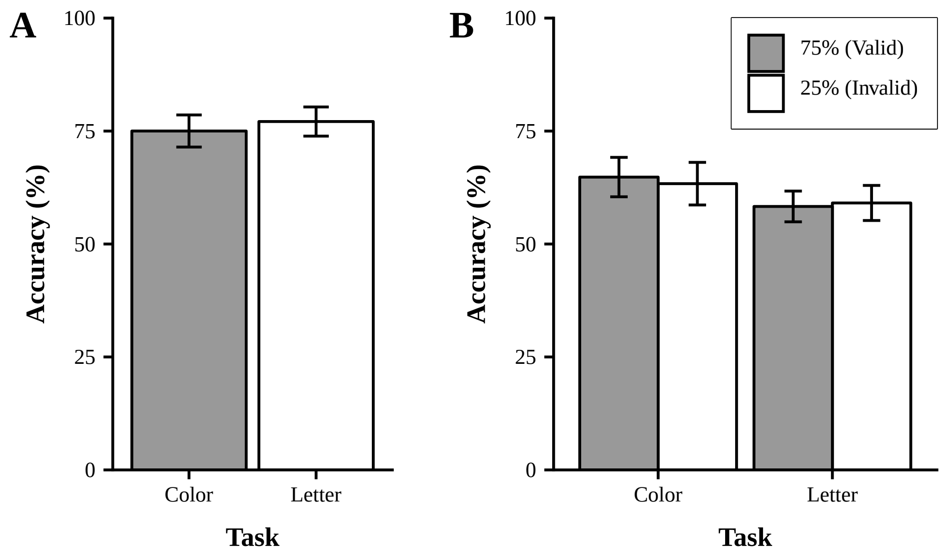

Figure 3. Results for the Training Phase (left) and Mixed Phase (right) from Experiment 2. Accuracy scores (%) for color and letter identification trials as a function of location cue validity.

everything" strategy in both locations. As a result, the locations may still be operating as effective cues, but they may be cuing the very same attentional control settings in both locations. The purpose of Experiment two was to establish a history of differential attentional processing in each location. This was achieved by including a blocked practice phase prior to the mixed trial phase. The practice phase consisted of a block of trials where a single identification task (e.g., color) was paired consistently with one location, followed by another block where the other identification task (e.g., letter) was paired consistently with the other location. Subjects were informed about the blocked practice phase and mixed phase experimental structure, but were not informed about the proportion manipulations.

Proportion congruent designs sometimes include a blocked practice phase to achieve context-specific attentional control. For example, Lehle and Hübner (2008) could only demonstrate contextual control over flanker effects when subjects received blocked practice first (see also Crump, 2016). This is consistent with the memory-driven account which requires a history of experiences where different attentional priorities were deployed in different situations. The blocked practice phase would allow subjects to adopt dimension-specific sampling strategies, and the mixed phase would allow us to test whether this training is required for producing contextual control.

Methods

Subjects. All subjects were Brooklyn College undergraduate students (approximately ages 18-22) who participated in this study for course credit. Twenty-one subjects completed Experiment 2.

Apparatus & Stimuli. The apparatus and stimuli were identical to Experiment 1.

Design. The design was similar to Experiment 1 except that subjects completed a blocked practice phase prior to the mixed phase. Experiment 2, therefore involved a one-way within-subjects practice phase with task as a factor (color identification vs. letter identification) and a separate 2x2 within-subjects design for the mixed phase with cue validity (75% vs. 25%) and task (color identification vs. letter identification) as factors. The high-proportion tasks assigned to each location (above or below the fixation) were randomly assigned across subjects. The locations assigned to each task in the blocked practice phase were kept consistent with the validity manipulation in the mixed phase. For example, if the above location was assigned to color during the block phase, the same location was assigned to be 75% color identification in the mixed phase. Whether the first practice block involved the color or letter location was randomly assigned across subjects.

There were a total of 512 trials. The first practice block included 128 trials, with all stimuli appearing in one location and requiring only one identification task. The second block repeated this procedure with the other location and identification task. The last two blocks (the mixed phase) consisted of 128 trials each, with 50% color and letter identification trials occurring with equal probability above or below the fixation. As with Experiment 1, one location (randomly assigned as above or below the fixation) consisted of 75% color identification trials (96 trials) and 25% letter identification trials (32 trials) while the other location consisted of 75% letter identification trials and 25% color identification trials. The trial sequence was randomized for each subject.

Procedure. The procedure was identical to Experiment 1.

Results

Mean accuracy scores for each subject in each condition are displayed in Figure 3. Mean RTs and accuracy scores for all experiments are displayed in Table 1.

Training Phase. Mean accuracy scores for each subject were submitted to a repeated-measures ANOVA with task (color identification vs. letter identification) as the sole factor. There was no significant difference between mean accuracy in the color identification block (M = 74.6%) and the letter identification block (M = 76.6%), $F(1, 20) = 0.29$, $MSE = 159.68$, $p = .597$, $\hat{\eta}^2_p = .014$.

Mixed Phase. Mean accuracy scores for each subject were submitted to a repeated-measures ANOVA with cue validity (75% vs. 25%) and task (color identification vs. letter identification) as factors. Both main effects for cue validity, $F(1, 20) = 0.04$, $MSE = 0.01$, $p = .847$, $\hat{\eta}^2_p = .002$ and task, $F(1, 20) = 1.96$, $MSE = 0.03$, $p = .177$, $\hat{\eta}^2_p = .089$ were non-significant. The two-way interaction between cue validity and task was also non-significant, $F(1, 20) = 0.46$, $MSE = 0.01$, $p = .505$, $\hat{\eta}^2_p = .023$. Subjects performed equally well on the valid and invalidly cued trials.

How performance compared between the mixed and training phases was also of interest. To address this question, overall accuracy scores from the mixed and training phases were submitted to a pairwise t-test and found that subjects performed significantly better in the Training Phase (M = 76%) than the Mixed Phase (M = 61%), $t(20) = -5.38$, $p < .001$.

Discussion

Experiment 2 again failed to demonstrate context-specific control over attentional priorities for sampling from color and letter dimensions in briefly presented displays. As with Experiment 1, in the mixed phase targets were not better identified on valid versus invalid trials.

However, accuracy was substantially better in the blocked practice phase than the mixed phase. One interpretation of this finding is that attentional priorities for sampling from letter vs. color dimensions can be set in a preparatory fashion, when subjects know in advance which dimension will be cued. On this view, our blocked phase would have successfully created a memory record that would be suitable for producing contextual control. That is, each subject would have a history of experiences where they prioritized the color dimension in one location and the letter dimension in the other. Yet, there was no evidence of contextual control in the mixed phase.

There are several possibilities for the absence of context-specific effects. Increased accuracy in the blocked phase may not reflect changes to attention, but could instead reflect general differences in task difficulty between blocked and mixed phases. Perhaps contextual control phenomena do not generalize to our bi-dimensional sampling task. Finally, it is possible that contextual control can be interfered with by intentional control. More specifically, even though subjects may have learned to assign different attentional priorities in each location during the blocked practice phase, when they were confronted with the trial-to-trial uncertainty of the upcoming identification task in the mixed phase, they may have intentionally deployed a "sample-everything" strategy, which could have superseded any contextual influences over setting attentional priorities.

Experiment 3

Experiment 3 investigated the role of intentions in producing contextual control. Subjects were made aware of the location-specific proportion manipulation and explicitly instructed to adopt and maintain differential attentional strategies in each location. Specifically, subjects were instructed to attend more to the colors in the color location and more to the letters in the letter location, as indicated by the training phase. Importantly, subjects were instructed to maintain the location-specific attentional priorities in the mixed phase. In this way, we tested whether or not context-specific differences in attentional priorities could be set by intentional means

Methods

Subjects. All subjects were Brooklyn College undergraduate students (approximately ages 18-22) who participated in this study for course credit. A total of 20 subjects completed Experiment 3.

Apparatus & Stimuli. The apparatus and stimuli were identical to the previous experiments.

Design. The design was identical to Experiment 2.

Procedure. The procedure was similar to Experiment 2, however in Experiment 3 subjects were made aware of the proportion manipulation and instructed to follow explicit strategies consistent with the predictiveness of the location cue. Specifically, they were instructed to maintain the strategy of "attend more to the letters in the letter location" and "attend more to the colors in the color location" as defined by their practice phase. In addition, they were told to do there best when they were asked to identify a dimension that was inconsistent with the strategy, but to continue the strategy.

Results

One concern with adopting this set of instructions was that subjects would ignore the task cues and always respond with the high-proportion task response set. For example, when the target display occurred in the 75% letter location, subjects may ignore the cue that says "Color?" and respond with a letter every trial. To determine which subjects may have adopted this strategy, we calculated the task accuracy for each subject in each condition. The task accuracy reflects the proportion of trials where a subject responded with one of the four appropriate response keys (letters when asked for a letter and colors when asked for a color) regardless of whether it was the correct response. Subjects with less than 25% task accuracy in any condition were not included in the analysis. This criterion was applied to all remaining analyses. For Experiment 3, this eliminated three subjects. Mean task accuracy for the remaining subjects was 96%.

Mean accuracy scores for each subject in each condition are displayed in Figure 4. Mean RTs and accuracy scores for all experiments are displayed in Table 1.

Training Phase. There was no significant difference between the mean accuracy in the color identification block (M = 79.8%) and the letter identification block (M = 81.9%), $F(1, 16) = 0.61$, $MSE = 64.60$, $p = .445$, $\hat{\eta}_p^2 = .037$.

Mixed Phase. Mean accuracy scores for each subject were submitted to a repeated-measures ANOVA with cue validity (75% vs. 25%) and task (color identification vs. letter identification) as factors. The critical main effect of cue validity was significant $F(1, 16) = 14.34$, $MSE = 0.01$, $p = .002$, $\hat{\eta}_p^2 = .473$. Additionally, the main effect for task was non-significant $F(1, 16) = 0.06$, $MSE = 0.03$, $p = .808$, $\hat{\eta}_p^2 = .004$, and the two-way interaction between cue validity and task was non-significant $F(1, 16) = 0.28$, $MSE = 0.01$, $p = .605$, $\hat{\eta}_p^2 = .017$. Subjects therefore performed better for both letter and color targets on valid than invalid trials.

Discussion

Experiment 3 successfully demonstrated that subjects can adjust attentional priorities for sampling from letter versus color dimensions between contexts in the mixed phase. It is possible that the adjustment of attentional priorities reflected contextual control processes, but they could also reflect rapid intentional control. That is, subjects could simply be following task instructions to deliberately change their attentional priorities in response to the location context in which a display occurs.

Experiment 4

Experiment 4 used a process-dissociation type logic (Jacoby, 1991) to isolate potential automatic and voluntary influences driving the context-specific effects found in Experiment 3. Like Experiments 2 and 3, Experiment 4 included a blocked practice and a mixed phase.

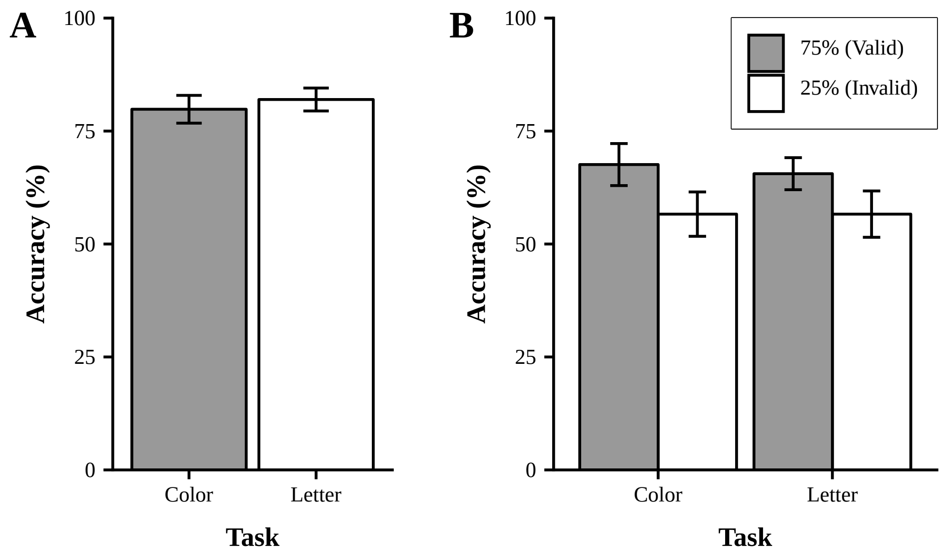

Figure 4. Results for the Training Phase (left) and Mixed Phase (right) from Experiment 3. Accuracy scores (%) for color and letter identification trials as a function of location cue validity.

However, the mixed phase contained two kinds of blocks that were either consistent or inconsistent with training. In the consistent blocks, the valid (75%) locations for color and letter tasks were consistent with training. In the inconsistent blocks, the valid locations were reversed from those used in training. Additionally, subjects were instructed throughout the experiment about which dimension should be attended to in each location. Subjects were always told which location was valid for both tasks, and were always instructed to prioritize each task in its respective predicted location for the current block. If the effects from Experiment 3 are due solely to volition, then subjects should be able to adjust their strategies appropriately even when those strategies are assigned to locations that were inconsistent with training. If on the other hand, subjects did form associations between location cues and intentionally set attentional priorities, then reversing the high-proportion tasks assigned to location contexts should interfere with context-specific effects by acting against intentional influences.

Methods

Subjects. All subjects were Brooklyn College undergraduate students (approximately ages 18-22) who participated in this study for course credit. Twenty-six subjects completed Experiment 4.

Apparatus & Stimuli. The apparatus and stimuli were identical to the previous experiments.

Design. The design was similar to Experiment 3 except that subjects completed blocks of trials where the high-proportion locations were reversed. This involved a practice phase with task as a factor (color identification vs. letter identification), and a separate 2x2x2 within-subjects design for the mixed phase with cued validity (75% vs. 25%), task (color identification vs. letter identification) and test blocks (trained context vs. reversed context) as factors. The high-proportion tasks assigned to each location (above or below the fixation) were randomly assigned across subjects. The locations assigned to each high-proportion task in the blocked practice phase were consistent with the trained context blocks and reversed in the reversed context blocks. Additionally, whether the first practice block involved the high-proportion color or high-proportion letter location was also randomly assigned across subjects.

There were 480 trials. The first practice block included 48 trials, with all stimuli appearing in one location and requiring only one identification task. The second block repeated this procedure with the other location and other identification task. The mixed phase involved four blocks of 96 trials with 50% color and letter identification trials occurring with equal probability above or below the fixation. One location (randomly assigned to above or below the fixation) consisted of 75% color identification trials and 25% letter identification trials while the other location consisted of 75% letter identification trials and 25% color identification trials. The first and third blocks were trained context blocks, in that the locations for the valid trials were consistent with those during training. The second and fourth blocks were reversed context blocks, in that the locations for the valid trials were reversed from those in the training phase. The trial sequence was randomized for each subject.

Procedure. The procedure was similar to Experiment 3, in that subjects were made aware of the proportion manipulation and instructed to follow explicit strategies to account for the predictiveness of the location cue. However, every 96 trials, the prompt would instruct them to reverse their strategies.

Results

As with Experiment 3, task accuracy was calculated for each subject and those with less than 25% were not included in the analysis. Accordingly, six subjects were eliminated from the following analysis. Mean task accuracy for the remaining subjects was 92%. Mean accuracy scores for each subject in each condition are displayed in Figure 5. Mean RTs and accuracy scores for all experiments are displayed in Table 1.

Training phase. Accuracy was significantly better in the letter identification task (M = 77.8%) than the letter identification block (M = 67.7%), $F(1, 19) = 10.48$, $MSE = 97.38$, $p = .004$, $\hat{\eta}^2_p = .356$.

Mixed phase. Mean accuracy scores for each subject were submitted to a repeated-measures ANOVA with cue validity (75% vs. 25%), task (color identification vs. letter identification) and test blocks (trained context vs. reversed context) as factors.

The three-way interaction between cue validity, task, and test blocks was non-significant, $F(1, 19) = 1.94$, $MSE = 0.00$, $p = .180$, $\hat{\eta}^2_p = .093$. However, the critical two-way interaction between cue validity and test blocks was significant $F(1, 19) = 5.25$, $MSE = 0.01$, $p = .034$, $\hat{\eta}^2_p = .217$, showing that the validity effect was larger during trained context test blocks compared to reversed context test blocks. To further analyze the significant two-way interaction, task was collapsed over and the reversed and trained context conditions were analyzed separately. A separate analysis of the trained context revealed significantly higher accuracy on valid (M = 57%) than invalid (M = 47%) trials,

$t(19) = 3.34$, $p = .003$. The analysis of the reversed context also showed higher accuracy on valid (M = 54%) than invalid (M = 50%) trials, $t(19) = 2.09$, $p = .050$.

For the sake of completeness: The two-way interaction between cue validity and task $F(1, 19) = 1.00$, $MSE = 0.01$, $p = .329$, $\hat{\eta}_p^2 = .050$, and task and test blocks, , were both non-significant. Finally, the main effect for cue validity was significant, $F(1, 19) = 9.85$, $MSE = 0.02$, $p = .005$, $\hat{\eta}_p^2 = .341$, and the main effects for both task $F(1, 19) = 0.98$, $MSE = 0.02$, $p = .335$, $\hat{\eta}_p^2 = .049$, and test blocks, $F(1, 19) = 0.00$, $MSE = 0.01$, $p = .991$, $\hat{\eta}_p^2 = .000$, were non-significant.

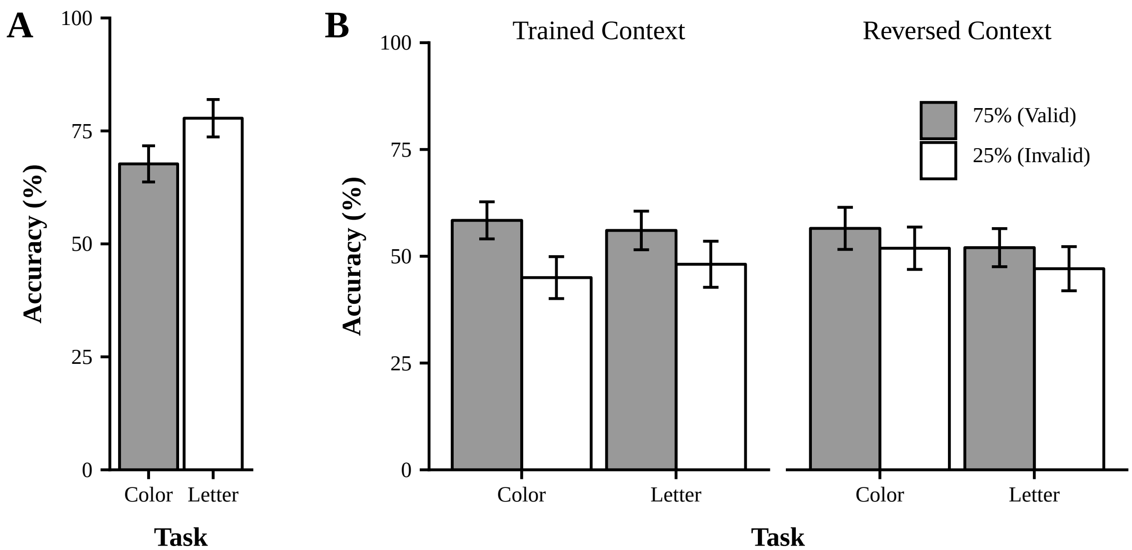

Figure 5. Results for the Training Phase (left) and Mixed Phase (right) from Experiment 4. Accuracy scores (%) for color and letter identification trials as a function of location cue validity.

Block analysis. Also of interest was whether the validity effects changed over the course of the experiment. We divided the test trials in half, examining the validity effects in the first half of the test trials (comprised of the first trained and reversed context blocks) and the second half (comprised of the second trained and reversed context blocks). A visual inspection of the results displayed in Figure 6 suggest a validity effect for the trained context block but not the reversed context block in the first half, and no validity effects for either the trained or reversed context blocks in the second half. This result was confirmed in the following statistical analyses. For the sake of brevity, only the critical tests are reported.

Mean accuracy scores were submitted to a repeated-measures ANOVA with test half (first half vs. second half), cue validity (75% vs. 25%), task (color identification vs. letter identification), and test block (trained context vs. reversed context) as factors. The four-way interaction was non-significant, $F(1, 19) = 0.01$, $MSE = 0.01$, $p = .926$, $\hat{\eta}_p^2 = .000$. However, the critical three-way interaction between test half, test block, and cue validity was significant, $F(1, 19) = 7.55$, $MSE = 0.02$, $p = .013$, $\hat{\eta}_p^2 = .284$.

To probe the three-way interaction, each test half (first and second) was analyzed separately, collapsing over task. Mean accuracy scores for each test half were submitted to a repeated measures ANOVA with cue validity (75% vs. 25%) and test block (trained context vs. reversed context) as factors.

First, we analyzed the first half and found a significant two-way interaction between cue validity and test block, $F(1, 19) = 18.27$, $MSE = 0.01$, $p < .001$, $\hat{\eta}_p^2 = .490$. Further analyses of the simple effects revealed significantly higher accuracy in the 75% (valid) trials (M = 57%) as compared to the 25% (invalid) trials (M = 37%) for the trained context, $t(19) = 4.62$, $p < .001$, and no significant difference between accuracy scores in the 75% (valid) and 25% (invalid) trials for the reversed context, $t(19) = 1.62$, $p = .121$.

An analysis of the second half revealed no significant two-way interaction between cue validity and test block, . The main effect of cue validity was also non-significant, $F(1, 19) = 2.23$, $MSE = 0.01$, $p = .152$, $\hat{\eta}_p^2 = .105$. The main effect of test block however, was significant, $F(1, 19) = 8.63$, $MSE = 0.01$, $p = .008$, $\hat{\eta}_p^2 = .312$.

To summarize, we analyzed the first and second halves of the test trials separately and found a significant validity effect for the trained context and no validity effect for the reversed context in the first half of the test trials. For the second half we found no significant validity effects across both the trained and reverse context test blocks.

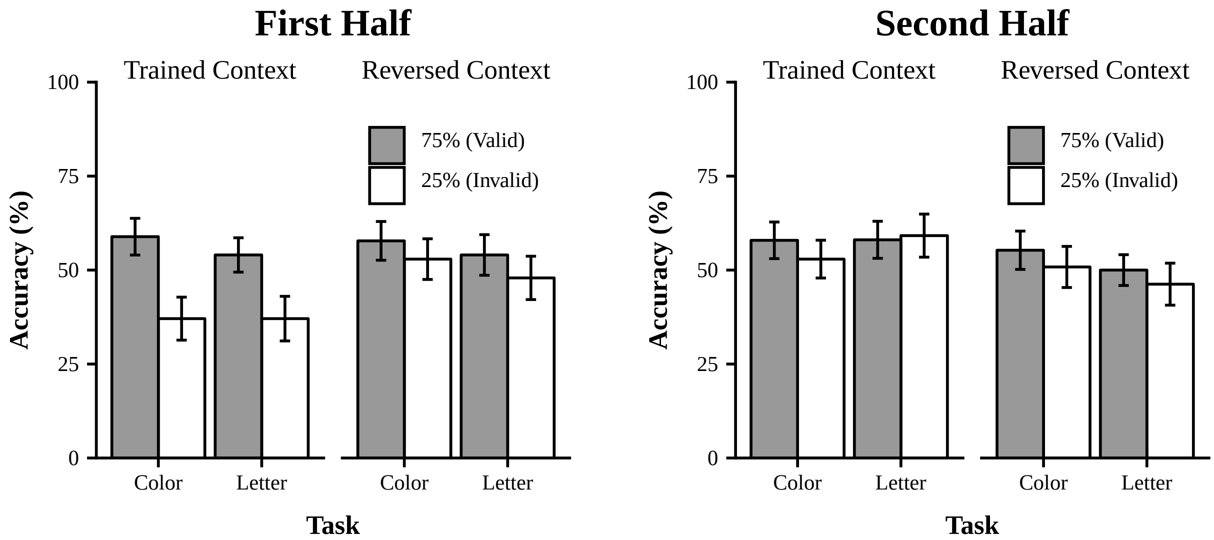

Figure 6. Results from Experiment 4 for the first (left) and second (right) halves of the Mixed Phase. Accuracy scores (%) as a function of task (color vs. letter), location cue validity (75% vs. 25%) and test blocks (trained context vs. reversed context)

Discussion

The results of Experiment 4 replicate the general findings of Experiment 3 showing that identification accuracy was higher on valid than invalid trials. The critical finding was that the validity effect depended on the nature of the test block. The validity effect was larger on trained context blocks compared to reversed context blocks. Trained context blocks assigned the 75% color and 75% letter task locations to the same locations used for each task during blocked practice. The reversed context blocks flipped the assignment with respect to blocked practice. As a reminder, prior to and during each test block subjects were always told which location predicted each task. They were also instructed to attend more to color in the location that predicted the color task, and more to letters in the location that predicted the letter task. If the validity effect was entirely driven by a flexible intentional control process, then we expected that process to produce equivalent validity effects regardless of whether the test block was consistent or reversed from training. Instead, we found smaller validity effects in the reversed context test blocks. One interpretation of this finding is that the associations between contextual cues and attentional strategies formed during training interfered with the deployment of intentional strategies during the reverse context test blocks. On this view, the results from Experiments 3 and 4 are not due solely to voluntary shifts in attentional prioritization, but also reflect some contribution of contextual control over setting of attentional priorities.

We also found significant changes in the validity effects from the first to second half of the test blocks. Specifically, there was only a validity effect in the first block of the trained context trials and there were no significant validity effects for the reversed context trials in either block. Our purpose in running Experiment 4 was to determine whether the results from Experiment 3 could be accounted for solely on the basis of volitional shifts in attentional prioritization. The block analysis then provides even less support for this idea that subjects could flexibly shift attentional priorities in the reversed context blocks because there was no evidence for any validity effect within each reversed block when analyzed separately. However, our design consisted of a fixed order of test blocks (trained, reversed, trained, reversed) and we only found validity effects in the first block. One possibility is that subjects were unable to continually deploy instructed strategies. Perhaps subjects lacked motivation to continue applying the instructed strategies or they were motivated but only had available resources to apply the effortful strategies for a short period of time. On this view, subjects could voluntarily shift attentional priorities but chose not to or were unable to maintain voluntary control over longer periods. However, we note that accuracy in general increased across blocks, which suggests that subjects became more motivated to perform well in the task.

Alternatively, the finding that the validity effects were only evident in the first test blocks could also reflect some contribution of contextual control over setting of attentional priorities. It is clear that in the first test block subjects did adopt the trained attentional strategy, but then failed to adopt the reversed strategy in the second block. One interpretation is that training provided the needed experiential support for enacting the strategy, and when that support was missing (for the reversed context blocks) strategic control was not possible. Similarly, the disappearance of the validity effect could be due to the fact that associations formed during training were extinguished during the mixed phase which involved many new trial types that were inconsistent with training. This interpretation fits with previous findings that effectively applying an attentional strategy for ignoring a distractor requires experiential learning, or practice with ignoring the distractor (Vecera, Cosman, Vatterott, & Roper, 2014). For example, Cunningham and Egeth (2016) examined whether subjects could make use of a pre-cue signaling the identity of an upcoming distractor for the purposes of ignoring the irrelevant feature when it appeared. They found that subjects learned to ignore distractors that were preceded by a consistent cue that always signaled the same distracting feature across trials. However, when the pre-cue signaled different distracting features across trials participants failed to benefit from the pre-cue for the purpose of ignoring the signaled distractor. Our results are similar in that subjects were able to transfer their learning from the practice blocks to the first test block which was mostly consistent with training. However, across test blocks attentional sampling demands became increasingly inconsistent with practice and prevented transfer of learning from the practice phase to test block performance.

General Discussion

In experiment one, one location involved 75% color and 25% letter identification trials and the other involved 75% letter and 25% color identification trials. Despite the fact that location predicted the likely task on each trial, we found no evidence of contextual control. Specifically, identification performance on validly cued trials was not different from invalidly cued trials. The automatic adaptation accounts posit learning processes sensitive to error- or conflict-driven signals; however, no evidence of contextual control was found in Experiment 1 despite the poor accuracy that should allow for such learning processes to operate. One explanation of the absence of contextual control was the suggestion that subjects adopted a “sample everything” strategy on every trial, and learned associations between location contexts and the attentional priorities assigned by the “sample everything” strategy.

In experiment two, the mixed phase was preceded by a blocked training phase where each identification task was performed consistently in a particular location. The blocked phase was included to ensure that subjects had experiences with deploying different attentional priorities between contexts. We found better identification performance in the blocked than the mixed phases. However, there was no validity effect in the mixed phase, indicating no evidence of contextual control. Although there was evidence that subjects did learn to assign different attentional priorities in the different contexts during the blocked practice, this learning apparently failed to transfer to control setting of attentional priorities in the mixed phase. One reason for the absence of contextual control in the mixed phase was that subjects again decided to adopt the “sample everything” strategy which could have overridden the ability of contextual cues to set attentional priorities.

In experiment three, we repeated the same design as experiment two, but made subjects aware of the validity manipulation and gave them instructions to attend more to color information in the 75% color location, and more to letter information in the 75% letter location. The major finding was the presence of a validity effect in the mixed phase, indicating that subjects were capable of assigning different attentional priorities between locations. However, it remained unclear whether this effect was mediated by cue-driven or intentional influences over setting of attentional priorities.

In experiment four, we included new test blocks in the mixed phase where the valid locations for the color and letter tasks were consistent or reversed from training. The critical finding was a larger validity effect when the locations were consistent rather than reversed from training. Here, the maintenance of voluntary attentional strategies was impaired when the strategies were inconsistent with the attentional priorities cued by location contexts established during training. This finding suggests that the validity effect in the mixed phase was not entirely driven by a flexible intentional process capable of setting attentional priorities according to instructions, but also reflects a contribution from contextual influences that control the setting of attentional priorities in a cue-driven fashion.

One general aim of the present work was to test guiding principles of contextual control by using a novel bi-dimensional sampling task. We found some cases where contextual control was not acquired or expressed in performance, and some cases where contextual control appeared to depend on previous experience with deploying different strategies for setting attentional priorities between contexts. We now turn to a discussion of the roles of awareness and intention in promoting contextual control, as well as a number of task differences between our procedure and previous ones that may explain the presence and absence of contextual control across our experiments.

Our findings depart from previous work showing that contextual control develops without awareness and intention. We consider two perspectives about how our findings relate to previous work. First, we may have found an exceptional case where contextual control does depend on experiences with intentionally adopting different attentional priorities in different contexts. On this view, contextual control can develop with or without intention, and whether or not contextual control relies on intention would be task-dependent.

Second, we consider the possibility that prior demonstrations of CSPC effects did depend on experiences with intentionally adopting different attentional priorities between contexts. A common finding in Stroop and flanker variants is that subjects are not aware of the CSPC manipulation. One interpretation of this finding is that subjects who were not aware of the manipulation did not intentionally use contextual cues to adopt different attentional priorities. However, we assume that subjects were always intentionally controlling attention priorities at the level of specific items, and that individual stimuli provoke subjects to adopt particular attentional priorities appropriate to the stimulus and task at hand. Consider the item-specific strategies adopted by a subject in CSPC Stroop task who is unaware of the CSPC manipulation, but who is following instructions to respond to a color dimension as quickly and accurately as possible. When a congruent item is presented, subjects may actively assign more priority to the word dimension because it matches with the correct color response. When an incongruent item is presented, subjects may actively assign less priority to the word dimensions because it does not match the correct color response. In this way, subjects may have intentions for setting attentional priorities at the item-specific level that can be exercised on each trial regardless of whether they are aware of the context-specific proportion congruent manipulation. As a result, the attentional priorities resulting from intentional control at the item-level could become associated with the contexts in which items frequently occur, thereby leading to the development of contextual control.

In order to entertain the view that intentional control does influence the acquisition of contextual control across tasks, we also need to consider discrepancies in the effectiveness of instructional manipulations. We show that subjects can follow instructions to adopt context-specific attentional priorities in the bi-dimensional sampling task. However, similar instructional manipulations were not effective in a CSPC Stroop task (Crump et al., 2008). Here, subjects were encouraged to adopt context-specific attentional priorities in response to the shape context of a target stimulus. Subjects were aware of the CSPC manipulation and were instructed to adopt context-specific attentional priorities; nevertheless, no evidence of contextual control was obtained. One interpretation of this finding is that intentional control is not sufficient for producing contextual control. However, it remains unclear whether those subjects could follow the instructions. For example, in their prime-probe Stroop task the subject was briefly presented with a word that disappeared before the target color patch was displayed in one of two shapes. The instruction was to use the shape cue to rely more or less on the previous word to help with responding to the color of the target. It is not clear how subjects would attempt to retrospectively ignore the influence of an already presented word. Therefore, intentional control may have failed to influence the acquisition of contextual control in those tasks because subjects were never engaging in context-specific intentional control to begin with. By contrast, in the current task the instruction to attend more to the colors versus the letters may be easier to communicate, more readily understood, and easier to execute than instructions employed in prior tasks.

Finally, there are critical differences between our task and those that have previously demonstrated contextual control. Though the current study suggests that intentional control may be a pre-requisite for the acquisition of contextual control, these task differences could potentially limit the generalizability of our findings and warrant further discussion.

Contextual control has been observed in several interference tasks where there is response conflict between target and distractor dimensions. In contrast, there was no apparent response conflict between our color and letter dimensions. Some theories of contextual control assume that the presence of this conflict drives learning and mediates the acquisition of contextual control (Blais et al., 2012; Botvinick et al., 2001; Verguts & Notebaert, 2008, 2009). For example, Crump et al. (2008) showed no CSPC effects in a Stroop task where subjects named words rather than colors. If contextual control depends on the presence of response conflict between target and distractor dimension, then the absence of contextual control in experiments one and two could be due to the absence of similar kinds of conflict in our task.

At the same time, we assume that our displays prompted ubiquitous response competition on each trial. Target displays consisted of four unique letters and colors and therefore on any given trial, eight potential responses. Additionally, the total amount of response competition could have been reduced substantially (from eight to four) to the extent that contextual cues signaled selective processing of the dimension that was usually probed in that location. On this view, if the acquisition of contextual control is strongly related to the size of the conflict signal, we would have expected rapid learning and strong evidence for contextual control in our first experiments.

Alternatively, it is possible that the high degree of response conflict prevented the acquisition of contextual control. Prior work has demonstrated an absence of contextual control when subjects failed to attend to contextual information. For example, Crump, Gong, and Milliken (2006) could only find evidence for contextual control using shape cues when subjects were given a secondary task that required them to explicitly attend to the shapes. This suggests that contextual information may need to be attended to and integrated with target information in order for contextual control to develop. The high degree of response conflict in our task may have limited the amount of attention subjects could direct to the contextual features or caused a failure in the stimulus-context integration process; both of which could explain the absence of contextual control in our experiments.

The time-course of stimulus presentation relative to the contextual cues may also influence the acquisition of contextual control. In our experiments we always presented the target display simultaneously with the contextual cue. Simultaneous presentation has been effective in demonstrating contextual control in Stroop and flanker tasks (Bugg & Crump, 2012). In general, prior work has not systematically explored how the time-course of contextual cueing influences the effectiveness of the cues. However, Reuss et al. (2014) presented the contextual cue either prior to or simultaneously with the target and found contextual control in both cases and Fischer, Gottschalk, and Dreisbach (2014) found contextual control developed more rapidly when the location-context was cued prior to the target. We could speculate however, that the effectiveness of the cue changes as a function of the timing relationships and it is possible that these changes are task-dependent. For example, simultaneous presentations may be effective in a Stroop or flanker task, but ineffective in a bi-dimensional sampling task such as ours. For this reason, it is possible that the absence of contextual control in our experiments was due to the fact that we used simultaneous presentations rather than advance presentations. In general, systematic investigation of time-course issues in any demonstration of contextual control is an important topic for future work.

Numerous studies show that attentional priorities for processing stimulus dimensions can be modulated by contextual cues (e.g., Corballis & Gratton, 2003; Crump, 2016; Crump et al., 2006, 2008; Gough et al., 2014; King et al., 2012). Furthermore, a growing body of literature has demonstrated that awareness of experimental manipulations such as dimensional-conflict, proportion of trial-types, and contextual cues, are not required to produce such effects (e.g., Heinemann et al., 2009; King et al., 2012; Panadero et al., 2015; Reuss et al., 2014; Sarmiento et al., 2012). This lack of awareness has suggested that contextual control can occur independent of a subject's intent. Our findings add to this body of work and show one situation where intentional setting of attentional priorities appears to be a pre-requisite for context-specific control. Our experiments also show that principles from theories of contextual control such as automatic error-driven learning, and automatic retrieval of prior instances do not necessarily generalize across tasks in a straightforward manner.

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