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Memory-Guided Selective Attention: Single Experiences With Conflict Have Long-Lasting Effects on Cognitive Control

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Adjustments in cognitive control, as measured by congruency sequence effects, are thought to be influenced by both external stimuli and internal goals. However, this dichotomy has often overshadowed the potential contribution of past experience stored in memory. Here, we examine the role of long-term episodic memory in guiding selective attention. Our aim was to demonstrate new evidence that selective attention can be modulated by long-term retrieval of stimulus-specific attentional control settings. All the experiments used a modified flanker task involving multiple unique stimuli. Critically, each stimulus was only presented twice during the experiment: first as a prime, and second as a probe. Experiments 1 and 2 varied the number of intervening trials between prime and probe and manipulated the amount of conflict using a secondary task. Experiment 3 ensured that specific colors assigned to prime stimuli were not repeated when presented as probes. Across both Experiments 1 and 2, we consistently found smaller congruency effects on probe trials when its associated prime trial was incongruent compared with congruent, demonstrating long-term congruency sequence effects. However, Experiment 3 showed no evidence for long-term effects. These findings suggest long-term preservation of selective attention processing at the episodic level, and implicate a role for memory in updating cognitive control.

Keywords: attention, memory, cognitive control, conflict adaptation, conflict monitor

Cognitive control enables flexible goal-directed behavior via attention and action selection processes that prioritize goal-relevant over irrelevant information. Attention is known to be strongly influenced by both external stimuli and internal goals. However, the strict dichotomy between stimulus-driven and goal-driven influences (Posner & Snyder, 1975; Schneider & Shiffrin, 1977; Shiffrin & Schneider, 1977) has downplayed the role of memory in guiding attention (Awh, Belopolsky, & Theeuwes, 2012; Hutchinson & Turk-Browne, 2012). People often reencounter similar objects, tasks, and environments that require similar cognitive control operations. A memory-retrieval process could shortcut the slow, effortful, and resource-demanding task of updating control settings by retrieving and reinstating the control procedures used in the past. Here we examine the role of long-term episodic memory in guiding selective attention.

Evidence for long-term, cue-driven retrieval of control operations has been reported in multiple attention paradigms, suggesting a general phenomenon. However, evidence within paradigms is limited to a small number of reports, and remains absent in conventional selective attention tasks, such as Stroop (1935) and Flanker (Eriksen & Eriksen, 1974), commonly used to make inferences about cognitive control processes. Our aim was to demonstrate new evidence that selective attention can be modulated by long-term retrieval of stimulus-specific attentional control settings, and then discuss implications of these findings for theories of cognitive control.

Long-Term Retrieval of Control Settings

Early evidence for long-term, cue-driven retrieval of attentional control settings was developed in the negative priming literature (for recent reviews, see D'Angelo, Thomson, Tipper, & Milliken, 2016; Frings, Schneider, & Fox, 2015). Negative priming refers generally to the finding that reaction times (RTs) to identify a previously ignored target are slowed compared with a target that was not previously ignored (Tipper, 1985). In a typical design, a prime display might include a to-be-named green target word (e.g., TRUCK) interleaved with a to-be-ignored red distractor word (e.g., PIANO). An immediately following probe display then presents a target/distractor pair, involving a target that was previously attended (attended repetition: TRUCK), previously ignored (ignored repetition: PIANO), or a word that was not attended or ignored (control: MOCHA). Negative priming is observed when ignored repetition RTs are slower than control trials. Early explanations of negative priming invoked a short-term, transient inhib-

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itory process: Ignoring a stimulus causes it to be briefly inhibited, and negative priming reflects the extra time needed to recover from inhibition during responding (Tipper, 1985; Tipper & Driver, 1988). However, two classes of findings were difficult to reconcile with the short-term inhibition explanation, and were formative for the idea that long-term, cue-driven memory processes may play a role in reinstating prior attentional control settings.

First, negative priming is sensitive to the match between probe and prime tasks, and can disappear when the probe task does not require selective attention to the target. The above task description involves selection in both prime and probe trials, as both trials present an interleaved target/distractor pair. If negative priming reflects carry-over of inhibition from the ignored distractor on the prime trial, then that inhibition ought to be detected on a following probe trial that presented the ignored distractor alone, as a single target. In this case, the probe trials do not require selection because only a single target is displayed. However, several experiments showed that negative priming is abolished when the probe display contains a single target (D. G. Lowe, 1979; Milliken, Joordens, Merikle, & Seiffert, 1998; Moore, 1994; Tipper & Cranston, 1985).

Second, negative priming can persist for long temporal intervals between a prime and probe trial. DeSchepper and Treisman (1996) demonstrated that negative priming in a shape discrimination task is observed up to 30 days between a prime trial (including a target and distractor shape), and a probe trial (including the previously ignored shape as the target). We are aware of only two other investigations of long-term negative priming. Lowe (1998) demonstrated negative priming persisting for 5 min, and Grison, Tipper, and Hewitt (2005), showed negative priming persisting over 54 intervening trials between a prime and probe.

Taken together, the findings that negative priming is sensitive to the match between probe and prime tasks, and that negative priming persists over the long-term, provided evidence suggesting a role for memory-based retrieval processes in negative priming. For example, inspired by instance-theories of memory (Hintzman, 1984; Logan, 1988), Neill and colleagues (Neill, 1997; Neill & Valdes, 1992; Neill, Valdes, Terry, & Gorfein, 1992) proposed an episodic retrieval account of negative priming. Here, an ignored distractor presented during a prime trial is tagged with a "do-not-respond" control operation. If the ignored distractor is presented as a target on the following probe trial, it could then retrieve its associated "do-not-respond" control operation, which would interfere with responding to that stimulus on the probe trial. Furthermore, because control operations associated with prime processing are preserved in an instance-based memory, they could be available (under the appropriate retrieval conditions) over the long-term.

Evidence for long-term retrieval of attention control settings, like those observed in negative priming, has been shown in a few different attention paradigms. These include long-term inhibition of return (Tipper, Grison, & Kessler, 2003), long-term retrieval of task-sets in task-switching (Waszak, Hommel, & Allport, 2003), long-term priming-of-pop out in visual search (Thomson & Milliken, 2012, 2013), and long-term response inhibition in stop-signal tasks (Verbruggen & Logan, 2008). It remains unclear whether this collection of evidence points to a general role for memory retrieval of control operations linked with specific prior processing episodes to update and adjust control operations in the present moment.

However, evidence for long-term retrieval of attention control settings has not been established in classic selective attention paradigms, such as Stroop and Flanker, commonly used to make inferences about cognitive control processes. A demonstration would be useful in its own right to further establish the generality of the phenomena and would test theories of control processes used to explain modulations to congruency effects. We outline theoretical implications for explanations of *n*-1 congruency sequence effects, and proportion congruent effects; and, then overview the procedures we adopted to measure long-term memory-based control of attention.

Congruency Effects

Congruency tasks measure target identification in the presence of potentially conflicting distractors. For example, in the Flanker task (Eriksen & Eriksen, 1974) participants are faster and more accurate to identify a center letter (e.g., "HHFHH") when flanking letters are congruent (e.g., "HHHHH") versus incongruent (e.g., "FFHFF") with the response. Modulations to the size of congruency effects can index the gain of attentional control assigned to target and distractor dimensions. For example, target information is assumed to be prioritized over distractor information when smaller versus larger congruency effects are observed.

Importantly, congruency effects are modulated by the history of previously experienced conflict. Congruency effects are reduced immediately following an incongruent trial, and when the proportion of incongruent trials is greater than the proportion of congruent trials. It is possible that both trial history effects could be explained by common principles, and some existing accounts have forwarded unified theories (Abrahamse, Braem, Notebaert, & Verguts, 2016; Egner, 2014; Verguts & Notebaert, 2008). We consider whether common principles invoked by the notion of long-term, cue-driven retrieval of attention control settings could explain congruency sequence and proportion congruent effects. Alternatively, memory-driven control could reflect a distinct influence that clarifies how different processes acting over the long- and short-term use prior experience with conflict to update control settings.

Congruency Sequence Effects

Congruency effects on trial *n* are smaller when trial *n*-1 contains an incongruent versus congruent trial (Gratton, Coles, & Donchin, 1992, for a review see Egner, 2007). Early explanations invoked voluntary control (Gratton et al., 1992), but recent findings suggest volition is not necessary. For example, congruency sequence effects can be produced despite contradictory expectations about the likelihood of conflict on the next trial (Jiménez & Méndez, 2013, 2014) and in the absence of awareness (Desender, Van Lierde, & Van den Bussche, 2013). Congruency sequence effects also occur over short timescales, persisting only for one or two trials (Akçay & Hazeltine, 2008; Mayr, Awh, & Laurey, 2003), quickly decaying with increased interstimulus or response-to-stimulus intervals, and eliminated all-together after 3- to 7-s intervals (Duthoo, Abrahamse, Braem, & Notebaert, 2014; Egner, Ely, & Grinband, 2010).

All accounts of congruency sequence effects assume that influences from a recent trial on current trial performance are transient and decay rapidly. Debate focuses on whether or not congruency sequence effects are driven by processes that change attentional control settings. Rapid decay is assumed by noncontrol accounts based on feature integration or event-binding processes (Hommel, 1998; Hommel, Müsseler, Aschersleben, & Prinz, 2001; Hommel, Proctor, & Vu, 2004), repetition priming (Mayr et al., 2003), and sequential contingency biases (Schmidt & De Houwer, 2011). Rapid decay is also assumed by control accounts based on conflict-monitoring theory (Botvinick, Braver, Barch, Carter, & Cohen, 2001). Here, a conflict-monitoring unit registers a transient conflict signal that triggers adjustments to attentional control settings which carry-forward to influence performance on the next trial.

There are notable parallels between the congruency sequence effect and negative priming. Like the congruency sequence, negative priming was assumed to operate on a transient, short-term basis. Although the congruency sequence can dissipate over the short-term, it remains unclear whether experiencing conflict on one trial can have long-term influences over congruency effects on future trials. There is some evidence that congruency sequence effects can accumulate in strength as a function of the number of preceding incongruent trials (Aben, Verguts, & Van den Bussche, 2017; Jiménez & Méndez, 2013; Rey-Mermet & Meier, 2017). However, there is no evidence, akin to long-term negative priming, showing that control operations applied on a single trial to a specific stimulus can be retrieved on a long-term basis to influence control operations to similar stimuli in the future. Another parallel is that congruency-sequence effects, like negative priming, can depend on the match between tasks performed on trial *n*-1 and trial *n*. For example, conflict experienced on trial *n*-1 in one interference task does not always cause modulations to congruency effects for a different task presented on trial *n* (for a review, see Braem, Abrahamse, Duthoo, & Notebaert, 2014).

These parallels motivated us to determine whether congruency sequence-like effects could extend across many intervening trials well beyond trial *n*-1. On the one hand, a finding of this nature could identify a memory-based attentional control process that is distinctly different from other short-term processes also capable of producing congruency sequence effects. On the other hand, perhaps memory-based retrieval of attention control settings could explain the short-term *n*-1 congruency sequence effect, especially if temporal similarity, along with item and context features are assumed to act as retrieval cues to apply control settings from recent trials (for similar perspectives, see Egner, 2014; Spapé & Hommel, 2008, 2014).

Proportion Congruent Effects

Proportion congruent effects show larger congruency effects for conditions associated with high rather than low proportions of congruent trials (for a review, see Bugg & Crump, 2012), and are demonstrated in list-wide, item-specific, and context-specific designs. In a Stroop variant, item-specific designs assign one set of items (e.g., red and blue combinations) to a high proportion congruent condition, and another set (e.g., green and yellow combinations) to a low proportion congruent condition. Both item types are intermixed randomly, so subjects cannot accurately predict whether the next trial will be congruent or incongruent. In these designs, congruency effects are found to be larger for high versus low proportion congruent item. Similarly, context-specific proportion congruent (CSPC) designs manipulate proportion congruent between two different contexts in which items can appear, again in a randomized, intermixed fashion. CSPC effects have been shown using location (Brosowsky & Crump, 2016; Corballis & Gratton, 2003; Crump, 2016; Crump, Brosowsky, & Milliken, 2017; Crump, Gong, & Milliken, 2006; Hübner & Mishra, 2016; Weidler & Bugg, 2016), font (Bugg, Jacoby, & Toth, 2008; Crump, 2016), shape (Crump, Vaquero, & Milliken, 2008), color (Vietze & Wendt, 2009), social categories (Cañadas, Rodríguez-Bailón, Milliken, & Lupiáñez, 2013), and incidental semantic cues (Blais, Harris, Sinanian, & Bunge, 2015). Again, congruency effects are larger for items appearing in high than low proportion congruent contexts. These trial history effects imply that item and context-specific cues become associated with attentional control settings, and that changes to attentional control can be triggered in a cue-driven manner.

We roughly group theories of item and context-specific proportion congruent effects into memory-based and conflict-monitoring accounts. Memory-based accounts invoke instance-based, long-term, cue-driven retrieval processes (Logan, 1988). Some proportion congruent designs are confounded by item-frequency, and may be explained simply by an event-learning process sensitive to the frequency of events (Schmidt, 2013; Schmidt & Besner, 2008). At the same time other designs show evidence that cues associated with proportion congruent can bias congruency effects even for frequency unbiased items (Crump et al., 2017; Crump & Milliken, 2009; though, see Hutcheon & Spieler, 2017). Here, memory-based accounts argue that attentional control settings are encoded during each processing experience, and are retrieved to update ongoing control operations in the present moment (Bugg & Hutchison, 2013; Crump, 2016; Crump et al., 2008). Conflict-monitoring accounts can explain item-specific proportion congruent effects by assuming that conflict-signals trigger adjustments to attentional control settings on an item-specific basis (Blais, Robidoux, Risko, & Besner, 2007; Verguts & Notebaert, 2008), and this kind of account could in principle be extended to explain context-specific proportion congruent effects.

There are clear parallels between early item-specific proportion congruent designs (Jacoby, Lindsay, & Hessels, 2003), and negative priming designs manipulating the application of attentional control sets on an item-specific basis (Milliken, Lupianez, Debner, & Abello, 1999). Indeed, the idea from negative priming that episodic retrieval processes are used to retrieve and reinstate prior attentional control sets was borrowed to explain proportion congruent effects. In the proportion congruent literature, however, there is no direct evidence supporting the core assumption of episodic retrieval theories that control operations from single-trials are stored in traces, or that single-traces could be retrieved to influence control operations for specific items on a long-term basis. For example, most proportion congruent designs use a small number of stimuli that are repeatedly presented over an experiment. It is unknown whether cues retrieve a single instance from among the available item repetitions or multiple instances that are aggregated during retrieval.

A demonstration that congruency effects could be modulated by the long-term retrieval of item-specific attention control settings has theoretical implications for proportion congruent effects. A positive demonstration would corroborate predictions from memory-based accounts, and challenge conflict-monitoring accounts that aggregate over item-specific control settings (Botvinick et al., 2001; Braver, 2012; De Pisapia & Braver, 2006; Jiang, Heller, & Egner, 2014).

Overview of Present Studies

Our experiments test whether a single experience with applying attentional control to a unique stimulus can be retrieved on a long-term basis to influence how attentional control is applied when the same stimulus is later. We reasoned that if the single prior experience is retrieved, it will influence performance on the current trial in a manner similar to the *n*-1 congruency sequence effect where smaller congruency effects are found following an incongruent as compared with congruent trial. In other words, we asked whether a congruency sequence-like effect could be observed on a long-term basis, when there are many intervening trials between a first and second experience with a unique stimulus.

All the experiments used a modified flanker task involving multiple unique stimuli. The designs were inspired by long-term negative priming where a unique target/distractor pair could be presented once as a prime stimulus, and once as a probe stimulus after any number of intervening trials. We created unique stimuli using a large bank of natural objects that could be displayed in different colors (Brady, Konkle, Gill, Oliva, & Alvarez, 2013). Each trial involved a row of objects, and the task was to identify the color of the central object as quickly and accurately as possible. Like other context-specific designs, the object feature dimension was irrelevant to the color-identification task. Each object was only presented once as a prime, either in a congruent or incongruent format, and once as a probe, either in a congruent or incongruent format. Across experiments we varied the number of intervening trials between prime and probe presentations. Our design allowed us to determine whether congruency effects for probe stimuli would vary as a function of prime congruency, indicating a long-term congruency sequence-like effect. Specifically, we measured whether the congruency effect for probe stimuli preceded by incongruent primes would be smaller than the congruency effect for probe stimuli preceded by congruent primes.

Experiments 1A, B, and C varied the number of intervening trials between prime and probe by five to 11 trials and manipulated the amount of conflict using a secondary task. Experiments 2a and b increased the number of intervening trials to an average of 160 trials. To foreshadow our results, we found clear evidence of a long-term congruency-sequence-like effect. Congruency effects for probes preceded by incongruent primes were smaller than congruency effects for probes preceded by congruent primes. Experiments 3a and 3b were conducted to test a long-term feature integration account, and ensured that specific colors assigned to prime stimuli were not repeated when presented as probes. These experiments showed no evidence of long-term congruency sequence-like effects.

Experiment 1A, 1B, and 1C

For Experiment 1, we report three replications of the same experimental design (see Figure 1). In all three experiments, the primary task was to identify the color of a central image (either blue or green) flanked on the left and right by the same image presented in either the same (congruent) or alternate color (incongruent). Each image was only presented twice during the experiment: once as a prime stimulus, and once as a probe stimulus. The trial order was constructed such that the distance between any given prime and probe stimulus always ranged from five to 11 trials (eight trials, on average). We chose to use a color flanker task so that congruency could be manipulated independently of the image representing the target and flanker stimuli such that we could repeat contextual images while alternating congruency.

The amount of conflict has been shown to influence the size of the *n*-1 congruency sequence effect (Forster, Carter, Cohen, & Cho, 2011; Wendt, Kiesel, Geringswald, Purmann, & Fischer, 2014; though see Weissman & Carp, 2013). It was unclear, however, whether the amount of conflict would influence our ability to detect long-term influences. For Experiment 1A, we used the basic design described above. For Experiments 1B and 1C, we included a secondary task to increase conflict and potentially improve our ability to detect the presence of long-term sequence effects. For the secondary task, we required participants to press the spacebar if the identity of the center image differed from the flankers. We reasoned that having participants continuously monitor for differing flanker and target images would cause them to attend more to the flanking images throughout the experiment and increase the overall level of conflict. This alternative task was randomly presented once for every eight normal trials.

Experiment 1C was a replication of Experiment 1B. A Monte-Carlo simulation analysis of the results from Experiment 1A suggested that doubling our trial count from 216 to 432 and increasing our subject count to 50 would increase our power to detect the long-term sequence effect from an estimated .7 to .95 (for a complete description of this procedure, see Crump et al., 2017). Therefore, for Experiment 1C the trial count was doubled and we collected data until we had 50 participants who completed all trials and maintained an error rate less than 20%.

Method

Participants. All participants were recruited from Amazon Mechanical Turk and compensated $1.00 (Experiment 1A and 1B) or $3.00 (Experiment 1C) for participating. The amount compensated was calculated by estimating the maximum amount of time required to complete each experiment and multiplying by $6.00 per hour. For each experiment the number of HITs (human intelligence tasks, an Amazon term for a work-unit) refers to the number of participants who initiated the study. Participants were included in the study if they completed all trials and each experiment consisted of unique participants. For Experiment 1A, 40 HITs were posted, and 40 participants completed all trials. For Experiment 1B, 40 HITs were posted, and 39 participants completed all trials, and for Experiment 1C, 55 HITs were posted, and 54 participants completed all trials.

Apparatus and stimuli. The experiments were programmed using JavaScript, CSS, and HTML. The program allowed participants to complete task only if they were running Safari, Google Chrome, or Firefox web browsers. Flanker stimuli were constructed using the 540 images created by Brady, Konkle, Gill, Oliva, and Alvarez (2013). Images were color rotated to either blue or green (for a more detailed description see Brady et al., 2013) and presented at 200 × 200 pixels. Each experiment ran as a

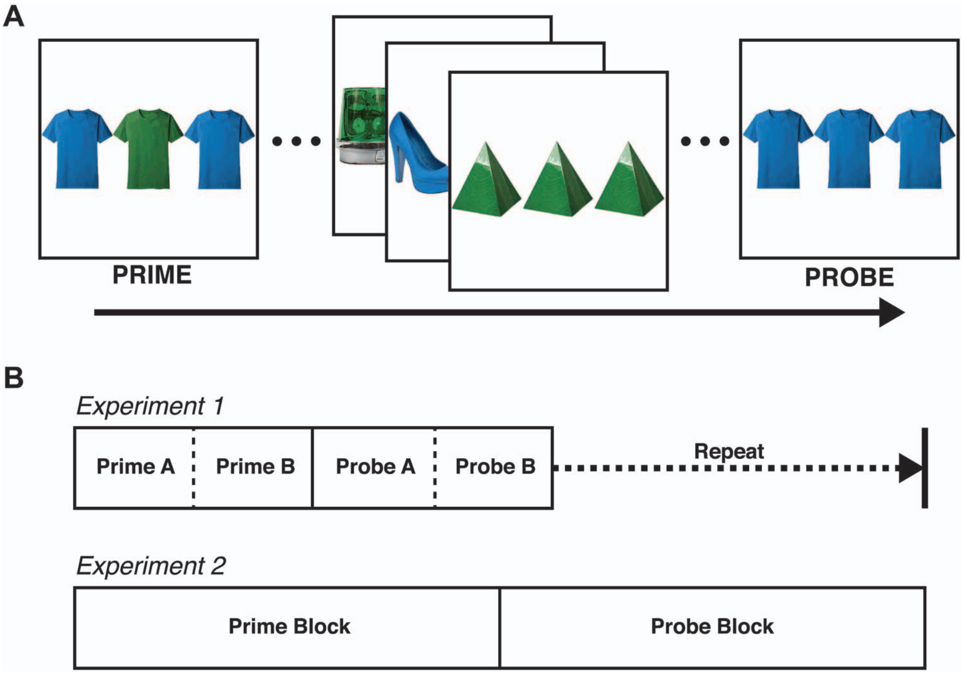

Figure 1. Figure 1A shows examples of the stimuli and basic prime/probe structure used in all experiments. Figure 1B shows the trial block structures from Experiments 1 and 2. In Experiment 1, every block of 16 trials was divided into four subblocks, each consisting of four trials (referred to as the Prime A, Prime B, Probe A, and Probe B subblocks). The images presented in the Prime A subblock were then repeated in the Probe A subblock and images presented in the Prime B subblock, repeated in the Probe B subblock. In Experiment 2, there were two blocks of trials, each consisting of 160 trials. The images presented in the Prime block were then repeated in the Probe block. See the online article for the color version of this figure.

pop-up window that filled the entire screen. The background was white, and stimuli were presented in the center of the screen.

Design. Experiment 1 used a 2 × 2 × 3 mixed design with prime congruency (congruent vs. incongruent) and probe congruency (congruent vs. incongruent) as within-subject factors, and experiment (1A, 1B, and 1C) as the between-subjects factor.

Experiments 1A, 1B, and 1C were all constructed using the same general method (see Figure 1). Every block of 16 trials was divided into four subblocks, each consisting of four trials (referred to as the Prime A, Prime B, Probe A, and Probe B subblocks). The images presented in the Prime A subblock were then repeated in the Probe A subblock and images presented in the Prime B subblock, repeated in the Probe B subblock. The trial order of each subblock was randomized. The use of the interleaved A/B subblocks ensured that the distance between any probe (trial *n*) and prime stimulus pair ranged from *n*-5 to *n*-11. Importantly, the congruency of each prime/probe pair was randomized and counterbalanced across each block with an equal number of each congruency combination (i.e., Con—Con, Con—Inc, Inc—Con, and Inc—Inc), and an equal number of response repetition and alternation prime/probe pairs. Additionally, images were randomly selected for every participant from the total 540 images (Brady et al., 2013) and randomly assigned a color and condition. Each image was only presented twice during the experiment: once in a prime block and once in a probe block.

Experiment 1A consisted of 192 trials constructed using this basic method. Experiment 1B used the same general design but included a secondary task where participants were instructed to press the spacebar if the center image differed in identity to the flanking images. This alternate task occurred once for every eight flanker trials, bringing the total trials to 216. Experiment 1C was identical to Experiment 1B except the number of trials was doubled, bringing the total to 432 trials.

Procedure. All participants were Amazon Mechanical Turk workers who found the experiment using the Amazon Mechanical Turk system. The participant recruitment procedure and tasks were approved by the Brooklyn College Institutional Review Board. Each participant read a short description of the task and gave consent by pressing a button acknowledging they had read the displayed consent form. Participants then completed a short demographic survey, and proceeded to the main task, which was displayed as a pop-up window. Participants were instructed to identify the color of the center image on each trial as quickly and accurately as possible by pressing "g" if the image was green, and "b" if the image was blue. For Experiments 1B and 1C, participants were further instructed to press the spacebar if the identity of the center image differed from the identity of the flanking images. Throughout the course of the experiment the upper left corner of the display indicated the number of completed and remaining trials, as well as an instruction reminder button that displayed the instructions in a new pop-up window.

Each trial began with a fixation cross presented in the center of the screen for 1,000 ms, followed by a blank interstimulus interval (ISI) of 250 ms. Next, the flanker stimulus appeared in the center of screen, and remained on screen until a response was made. Following a response, feedback indicating whether the response was correct or incorrect was presented above the target stimulus for 500 ms. For Experiments 1B and 1C, if the participant failed to press the spacebar on a secondary task trial, a message appeared below the target stimulus reminding the participant of the secondary task instructions. A response automatically triggered the next trial.

Halfway through Experiments 1A (96 trials) and 1B (108 trials), participants were instructed to take a short break, and to press the button on-screen when they were ready to continue. In Experiment 1C they received this message three times, each after they had completed 108 trials.

Results

Participants with mean error rates greater than 20% were excluded from the analyses. For Experiment 1A, this eliminated five participants, for 1B this eliminated seven participants, and for 1C this eliminated four participants. For all remaining participants, the RTs from correct trials in each condition were submitted to an outlier removal procedure (the nonrecursive procedure; Van Selst & Jolicoeur, 1994) that eliminated an average of 3.58%, 3.53%, and 3.11% of the observations from Experiments 1A, 1B, and 1C, respectively.

Long-term congruency sequence effects. The primary question of interest was whether the repetition of unique stimuli after a single presentation (trial *n*-5 to *n*-11) would produce sequential-like effects. To address this question, mean RTs from correct responses on the probe trials and error rates were submitted to a mixed analysis of variance (ANOVA) with prime congruency (congruent vs. incongruent) and probe congruency (congruent vs. incongruent) as within-subject factors, and experiment (1A, 1B, and 1C) as the between-subjects factor. (see Figure 2 and Table 1).

The results of the RT analysis revealed a significant two-way interaction between prime congruency and probe congruency, $F(1, 114) = 10.05$, $MSE = 1508.82$, $p = .002$, $\eta_p^2 = .08$, demonstrating a smaller congruency effect when the prime stimulus was incongruent rather than congruent. Furthermore, the three-way interaction between prime congruency, probe congruency, and experiment, was nonsignificant, $F(2, 114) = .11$, $MSE = 1508.82$ $p = .90$, $\eta_p^2 = .002$, showing no significant difference between the size or direction of the long-term sequence effects across experiments.

The results of the error analysis revealed no significant effects of interest. The three-way interaction between experiment, prime congruency, and probe congruency was nonsignificant, $F(1, 114) = .48$, $MSE = 11.17$, $p = .62$, $\eta_p^2 = .008$, and the two-way interaction between prime congruency and probe congruency was nonsignificant, $F(1, 114) = 1.39$, $MSE = 11.17$, $p = .24$, $\eta_p^2 = .01$. Average error rates from Experiments 1A, 1B, and 1C (probe trials only), were 4.38%, 3.29%, and 2.9%, respectively.

***n*-1 congruency sequence effects.** In our experimental design, specific stimuli never repeated trial-to-trial. Another question of interest was whether this design would still produce *n*-1 sequence effects when using nonrepeating stimuli. Some previous work has demonstrated that sequence effects were eliminated when contextual features alternate rather than repeat (Spapé & Hommel, 2008) whereas other studies using nonrepeating stimuli have successfully produced sequential effects (Egner et al., 2010; King, Korb, & Egner, 2012). To address this question, mean RTs from correct responses and error rates were submitted to a mixed analysis of variance (ANOVA) with trial *n*-1 congruency (congruent vs. incongruent) and trial *n* congruency (congruent vs. incongruent) as within-subject factors, and experiment (1A, 1B, and 1C) as the between-subjects factor (see Figure 2 and Table 2).

Two results of the RT analysis are of particular interest. First, the two-way interaction between trial *n* congruency and experiment was significant, $F(2, 114) = 11$, $MSE = 1743.37$, $p = .04$, $\eta_p^2 = .06$, suggesting the size of the congruency effect differed across experiments. Specifically, the congruency effect was smallest in Experiment 1A ($M = 33$ ms), then Experiment 1C ($M = 50$ ms), and largest in Experiment 1B ($M = 60$ ms).

Second, the critical two-way interaction between trial *n*-1 congruency and trial *n* congruency was significant, $F(1, 114) = 11$, $MSE = 1023.99$, $p = .001$, $\eta_p^2 = .09$ showing a smaller congruency effect when trial *n*-1 was incongruent compared to congruent. However, this interaction was qualified by a significant three-way

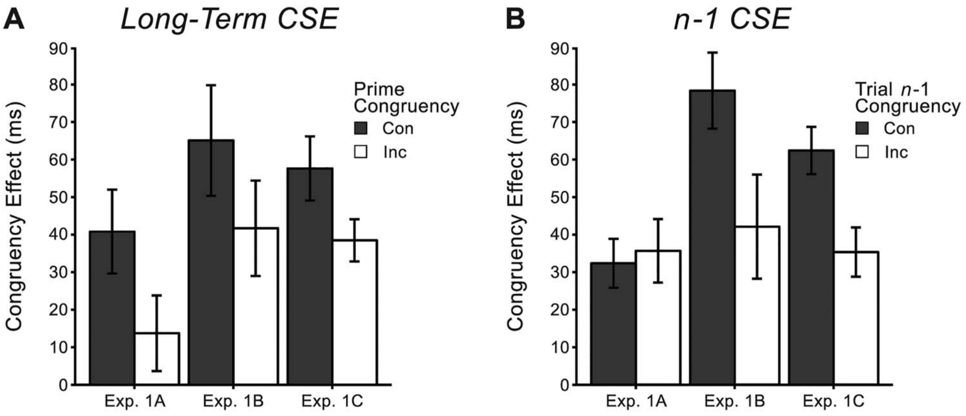

Figure 2. Results of Experiment 1. Figure 2A shows congruency effects in RTs as a function of prime congruency (congruent and incongruent) and experiment (A, B, and C). Figure 2B shows congruency effects in RTs as a function of trial *n*-1 congruency (congruent and incongruent) and experiment (A, B, and C). Error bars represent the standard error of the mean (SEM).

Table 1
Long-Term Congruency Sequence Effects for Experiments 1–3

	Probe				Congruency effect	Long-term CSE
	Con		Inc		(I - C)	$(C_{(I - C)} - I_{(I - C)})$
Prime	RT	ER	RT	ER	RT	RT
Exp. 1A						
Con	623 (23)	5.00 (.08)	664 (24)	5.12 (.71)	41 (11)	27 (14)
Inc	632 (22)	3.69 (.74)	646 (22)	3.69 (.68)	14 (10)	
Exp. 1B						
Con	766 (22)	3.78 (.71)	831 (25)	2.21 (.53)	65 (15)	23 (16)
Inc	779 (27)	3.65 (.69)	829 (21)	3.52 (.90)	42 (13)	
Exp. 1C						
Con	774 (26)	2.88 (.44)	831 (28)	2.21 (.42)	58 (9)	19 (9)
Inc	773 (26)	3.12 (.47)	812 (27)	3.38 (.51)	39 (6)	
Exp. 2A						
Con	566 (20)	2.99 (.55)	605 (21)	4.17 (.68)	39 (6)	21 (9)
Inc	575 (21)	2.64 (.43)	593 (19)	4.31 (.55)	18 (7)	
Exp. 2B						
Con	589 (22)	1.97 (.38)	647 (21)	4.34 (.66)	58 (8)	17 (11)
Inc	590 (23)	2.43 (.38)	630 (19)	3.95 (.68)	41 (11)	
Exp. 3A						
Con	842 (21)	2.37 (.50)	880 (22)	3.03 (.63)	38 (8)	13 (14)
Inc	846 (24)	2.84 (.55)	871 (21)	2.94 (.56)	25 (11)	
Exp. 3B						
Con	837 (22)	2.73 (.45)	867 (20)	2.50 (.48)	30 (7)	0 (10)
Inc	840 (22)	1.92 (.39)	870 (23)	2.15 (.47)	30 (7)	

Note. RT = reaction times (ms); ER = error rates (%); Con/C = congruent; Inc/I = incongruent; standard errors are presented in parentheses.

interaction between trial *n*-1 congruency, trial *n* congruency, and experiment, $F(2, 114) = 3.65$, $MSE = 1023.99$, $p = .03$, $\eta_p^2 = .06$.

To further probe the three-way interaction, we analyzed each of the experiments separately. The analysis of Experiment 1A resulted in no significant interaction between trial *n*-1 congruency and trial *n* congruency, $F(1, 34) < .01$, $MSE = 1364.48$, $p = .79$, $\eta_p^2 < .01$, suggesting no sequence effects. However, there were significant two-way interactions between trial *n*-1 congruency and

Table 2
n-1 Congruency Sequence Effects for Experiments 1–3

	Trial *n*				Congruency effect	*n*-1 CSE
	Con		Inc		(I - C)	$(C_{(I - C)} - I_{(I - C)})$
Trial *n*-1	RT	ER	RT	ER	RT	RT
Exp. 1A						
Con	626 (22)	2.97 (.55)	658 (22)	3.48 (.48)	32 (7)	−3 (13)
Inc	635 (21)	3.55 (.46)	671 (25)	4.48 (.72)	36 (9)	
Exp. 1B						
Con	753 (21)	2.40 (.51)	832 (25)	3.48 (.53)	78 (10)	36 (12)
Inc	791 (24)	3.58 (.54)	671 (25)	3.23 (.71)	42 (14)	
Exp. 1C						
Con	771 (27)	2.46 (.37)	834 (27)	2.66 (.39)	62 (6)	27 (7)
Inc	794 (25)	2.91 (.40)	829 (26)	2.65 (.38)	35 (7)	
Exp. 2A						
Con	557 (17)	2.36 (.38)	593 (16)	4.36 (.57)	36 (6)	8 (8)
Inc	576 (18)	3.59 (.47)	605 (19)	3.80 (.60)	28 (6)	
Exp. 2B						
Con	568 (20)	1.91 (.37)	638 (24)	4.67 (.61)	70 (5)	33 (6)
Inc	606 (24)	2.83 (.41)	643 (23)	3.78 (.58)	37 (7)	
Exp. 3A						
Con	837 (24)	2.18 (.45)	880 (20)	2.65 (.41)	43 (8)	22 (12)
Inc	855 (21)	2.83 (.40)	876 (22)	2.85 (.56)	20 (8)	
Exp. 3B						
Con	860 (23)	2.54 (.38)	889 (24)	2.38 (.42)	30 (7)	13 (10)
Inc	873 (24)	2.28 (.36)	889 (23)	2.43 (.35)	16 (8)	

Note. RT = reaction times (ms); ER = error rates (%); Con/C = congruent; Inc/I = incongruent; standard errors are presented in parentheses.

trial *n* congruency for both Experiment 1B, $F(1, 31) = 8.56$, $MSE = 1226.6$, $p = .006$, $\eta_p^2 = .22$, and Experiment 1C, $F(1, 49) = 13.87$, $MSE = 659.55$, $p < .001$, $\eta_p^2 = .22$, showing a smaller congruency effect following incongruent rather than congruent trials.

The results of the error analysis revealed no significant effects of interest. The three-way interaction between experiment, prime congruency, and probe congruency was nonsignificant, $F(1, 114) = .97$, $MSE = 7.1$, $p = .38$, $\eta_p^2 = .02$, and the two-way interaction between trial *n*-1 congruency and trial *n* congruency was nonsignificant, $F(1, 114) = .91$, $MSE = 7.1$, $p = .34$, $\eta_p^2 = .008$. Average error rates from Experiments 1A, 1B, and 1C, were 3.62%, 3.18%, and 2.67%, respectively.

Discussion

Across three replications, we found that a single experience with a unique stimulus could influence performance five to 11 trials after the initial presentation. Specifically, we consistently found smaller congruency effects for the probe when the first prime presentation was incongruent as compared with congruent, demonstrating a long-term congruency sequence effect. This result is consistent with the instance-based memory account suggesting that contextual features (image identity) could cue the rapid adjustment of attentional priorities after only a single prior presentation.

An unlikely, but alternative interpretation is that the decaying control signal carried forward over trials from the first presentation to influence the second. *n*-1 congruency sequence effects are often interpreted as the result of control settings or conflict signals from trial *n*-1 carrying forward to influence trial *n*. Various studies have shown that sequence effects, given the right conditions, can persist longer than one trial, from two to four trials (Jiménez & Méndez, 2013; Mayr et al., 2003), and up to 5 s (Egner et al., 2010) after the initial presentation. On the one hand, this interpretation seems unlikely given the intervening length in our experiments was much longer than previous demonstrations. On the other hand, the rate of decay is not well understood and certainly conflict-monitoring models are flexible in terms of the speed of decay (e.g., Botvinick et al., 2001; Braver, 2012). Additionally, there is evidence that under some conditions the rate of decay could be slowed. For example, one study demonstrated that the use of proactive strategies could prevent the sequence effect from decaying as rapidly as previously demonstrated (Duthoo et al., 2014). It is possible that the use of contextual cues combined with the frequency and regularity by which they repeated created some expectation for when contextual cues would repeat. This may have promoted the use of proactive strategies that slowed the decay rate long enough to produce our long-term sequence effect.

An additional consideration is whether the secondary task influenced performance in Experiments 1B and 1C. The secondary task had participants monitor the flanking images and press the spacebar when the flanking images differed in identity to the target image. The use of contextual cues in attention tasks is often thought to develop automatically (e.g., Chun & Jiang, 1998). However, there have been demonstrations using proportion congruent designs where context-dependency fails to develop without specific task instructions to engage in specific strategies (e.g., Brosowsky & Crump, 2016; Crump et al., 2008). The nature of our secondary task could have caused participants to attend more to the identities of the images and encouraged the use of contextual cues. Regardless, the long-term congruency sequence effect was also found in Experiment 1A where participants did not have the secondary task. So, although it may be possible that the secondary task contributed to the effects in Experiments 1B and 1C, removing the secondary task was not sufficient for eliminating the long-term sequence effect.

Finally, Experiments 1B and 1C included a secondary task to increase the amount of conflict, as measured by the congruency effect. Consistent with that manipulation, we found a smaller congruency effect in Experiment 1A as compared with 1B and 1C. However, the long-term sequence effect appeared to be insensitive to the conflict manipulation as we found no significant differences in the size of the long-term sequence effect across experiments. In contrast, we only found *n*-1 congruency sequence effects in Experiments 1B and 1C. These findings are consistent with prior work demonstrating the *n*-1 sequence effect despite the use of nonrepeating stimuli (Egner et al., 2010; King et al., 2012), and consistent with prior work showing a sensitivity to the amount of conflict (Forster et al., 2011; Wendt et al., 2014).

Experiment 2A and 2B

In Experiment 1, across three replications, we found long-term congruency sequence effects when there were five to 11 intervening trials between the first and second presentation of a unique stimulus. The goals of Experiment 2 were to conceptually replicate and extend the findings from Experiment 2 by increasing the number of intervening trials between the prime and probe pairs, increasing the variability in the frequency of stimulus repetition, and including an alternate conflict manipulation.

For both Experiments 2A and 2B, the primary task was the same as Experiment 1 which involved identifying the color of a central image (either blue or green) flanked on the left and right by the same image presented in either the same (congruent) or the alternate color (incongruent). Each image was only presented once as a prime stimulus, and once as a probe stimulus. Importantly, the experiment consisted of two blocks of 160 trials: a prime block followed by a probe block. Each block was randomized such that the distance between any given prime and probe stimulus ranged from one to 319 trials (160 trials, on average). To increase conflict in Experiment 2B, the flanking images preceded the target image by 100 ms, a manipulation known to increase the congruency effect (Wendt et al., 2014).

Method

Participants. All participants were recruited from Amazon Mechanical Turk and compensated $2.00 for participating. The amount compensated was calculated by estimating the maximum amount of time required to complete each experiment and multiplying by $6.00 per hour. For each experiment the number of HITs refers to the number of participants who initiated the study and each experiment consisted of unique participants. Participants were included in the study if they completed all trials. For Experiment 2A, 40 HITs were posted, and 39 participants completed all trials. For Experiment 2B, 40 HITs were posted, and 40 participants completed all trials.

Apparatus and stimuli. The apparatus and stimuli were identical to those used in Experiment 1.

Design. Experiment 2 used a 2 × 2 × 2 mixed design with prime congruency (congruent vs. incongruent) and probe congruency (congruent vs. incongruent) as within-subject factors, and experiment (2A and 2B) as the between-subjects factor.

Experiments 2A and 2B were both constructed using the same general method. Both experiments consisted of 320 total trials divided into two halves, a prime block and probe block. The prime block was constructed using 160 unique images randomly selected for each participant from the total 540 images (Brady et al., 2013). The images presented in the prime block were then repeated in the probe block. The trial order for each block was randomized, so the distance between any given probe (trial *n*) and prime stimulus paired ranged from *n*-1 to *n*-319. Each experiment consisted of 50% congruent/incongruent trials, an equal number of each congruency combination between prime/probe pairs (i.e., Con—Con, Con—Inc, Inc—Inc, and Inc—Con), and an equal number of response repetition and response alternation prime/probe pairs.

Procedure. All participants were Amazon Mechanical Turk workers who found the experiment using the Amazon Mechanical Turk system. The participant recruitment procedure and tasks were approved by the Brooklyn College Institutional Review Board. Each participant read a short description of the task and gave consent by pressing a button acknowledging they had read the displayed consent form. Participants then completed a short demographic survey, and proceeded to the main task, which was displayed as a pop-up window. Participants were instructed to identify the color of the center image on each trial as quickly and accurately as possible by pressing "g" if the image was green, and "b" if the image was blue. Throughout the course of the experiment the upper left corner of the display indicated the number of completed and remaining trials, as well as an instruction reminder button that displayed the instructions in a new pop-up window.

For Experiment 2A, each trial began with a fixation cross presented in the center of the screen for 1,000 ms, followed by a blank ISI of 250 ms. Next, the flanker stimulus appeared in the center of screen, and remained on screen until a response was made. Feedback indicating whether the answer was correct or incorrect was presented above the target stimulus following a response and remained on-screen for 500 ms which automatically triggered the next trial. For Experiment 2B, each trial began with a fixation cross presented in the center of the screen for 1,000 ms, followed by a blank ISI of 250 ms. Next, the flanking images appeared for 100 ms followed by the presentation of the center image. All images remained on screen until a response was given. Feedback indicating whether the answer was correct or incorrect was presented above the target stimulus following a response and remained on-screen for 500 ms which automatically triggered the next trial. In both experiments, after every 80 trials, a message appeared on-screen that instructed participants to take a short break and to press the button when they were ready to continue.

Results

Participants with mean error rates greater than 20% were excluded from the analyses. For Experiment 2A, this eliminated three participants and for 2B this eliminated two participants. For all remaining participants, the RTs from correct trials in each condition were submitted to an outlier removal procedure (the nonrecursive procedure; Van Selst & Jolicoeur, 1994) that eliminated an average of 3.2% and 3.3% of the observations from Experiments 2A and 2B, respectively.

Long-term congruency sequence effects. Mean RTs from correct responses on probe trials and error rates were submitted to a mixed analysis of variance (ANOVA) with prime congruency (congruent vs. incongruent) and probe congruency (congruent vs. incongruent) as within-subject factors, and experiment (2A and 2B) as the between-subjects factor (see Figure 3 and Table 1).

The results of the RT analysis revealed a significant two-way interaction between prime congruency and probe congruency, $F(1, 72) = 6.99$, $MSE = 980.13$, $p = .01$, $\eta_p^2 = .09$, demonstrating a smaller congruency effect when the prime stimulus was incongruent rather than congruent. Additionally, the three-way interaction between prime congruency, probe congruency, and experiment, was nonsignificant, $F(1, 72) = .09$, $MSE = 980.13$, $p = .77$, $\eta_p^2 = .001$, showing no difference between the size or direction of the long-term sequence effects across experiments.

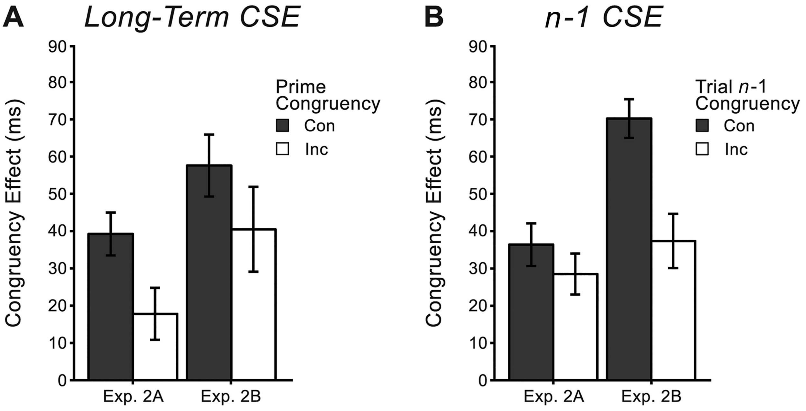

Figure 3. Results of Experiment 2. Figure 3A shows congruency effects in RTs as a function of prime congruency (congruent and incongruent) and experiment (A and B). Figure 3B shows congruency effects in RTs as a function of trial *n*-1 congruency (congruent and incongruent) and experiment (A and B). Error bars represent the standard error of the mean (SEM).

The results of the error analysis revealed no significant effects of interest. The three-way interaction between experiment, prime congruency, and probe congruency was nonsignificant, $F(1, 72) = 1.23$, $MSE = 6.77$, $p = .27$, $\eta_p^2 = .02$, and the two-way interaction between prime congruency and probe congruency was nonsignificant, $F(1, 72) = .09$, $MSE = 6.77$, $p = .76$, $\eta_p^2 = .001$. Average error rates from Experiments 2A and 2C (probe trials only), were 3.52% and 3.17%, respectively.

***n*-1 congruency sequence effects.** Mean RTs from correct responses and mean error rates were submitted to a mixed analysis of variance (ANOVA) with trial *n*-1 congruency (congruent vs. incongruent) and trial *n* congruency (congruent vs. incongruent) as within-subject factors, and experiment (2A and 2B) as the between-subjects factor (see Figure 3 and Table 2).

The RT analysis resulted in a significant two-way interaction between trial *n* congruency and experiment, $F(1, 72) = 9.9$, $MSE = 851.61$, $p = .002$, $\eta_p^2 = .12$. The size of the congruency effect was significantly smaller in Experiment 2A ($M = 33$ ms), as compared with Experiment 2B ($M = 54$ ms).

The critical two-way interaction between trial *n*-1 congruency and trial *n* congruency was also significant, $F(1, 72) = 15.92$, $MSE = 481.26$, $p < .001$, $\eta_p^2 = .18$, demonstrating a smaller congruency effect when trial *n*-1 was incongruent rather than congruent. However, this was qualified by a three-way interaction between trial *n*-1 congruency, trial *n* congruency, and experiment, $F(1, 72) = 5.99$, $MSE = 481.26$, $p = .02$, $\eta_p^2 = .08$.

A separate analysis of Experiment 2A showed no significant interaction between trial *n*-1 congruency and trial *n* congruency, $F(1, 35) = .91$, $MSE = 719.14$, $p = .35$, $\eta_p^2 = .03$. However, the analysis of Experiment 2B showed a significant two-way interaction, $F(1, 37) = 28.87$, $MSE = 355.08$, $p < .0001$, $\eta_p^2 = .44$, with a smaller congruency effect when trial *n*-1 was incongruent rather than congruent.

The results of the error analysis revealed a significant two-way interaction between trial *n*-1 congruency and trial *n* congruency, $F(1, 72) = 13.69$, $MSE = 4.35$, $p < .001$, $\eta_p^2 = .16$, showing a larger congruency effect following a congruent ($M = 2.37\%$), as compared with an incongruent trial ($M = 0.57\%$). However, the three-way interaction between experiment, trial *n*-1 congruency, and trial *n* congruency was nonsignificant, $F(1, 72) < .01$, $MSE = 4.35$, $p = .98$, $\eta_p^2 < .0001$. Average error rates from Experiments 2A and 2C, were 3.53% and 3.3%, respectively.

Discussion

The critical result in Experiment 2 was that congruency effects were significantly smaller on probe trials paired with an incongruent as compared with congruent prime trial. Experiment 2 therefore conceptually replicates Experiment 1, and demonstrates long-term congruency sequence effects with one to 319 intervening trials, increased variability in the frequency of stimulus repetition, and an alternate conflict manipulation.

Additionally, the level of conflict was manipulated across experiments. Consistent with our manipulation, the congruency effect was significantly larger in Experiment 2B as compared with 2A. However, this manipulation did not modulate the size or direction of the long-term congruency sequence effect. In contrast, we only found *n*-1 congruency sequence effects in Experiment 2B, suggesting a sensitivity to the level of conflict, and replicating the results of Experiment 1.

Experiment 3A and 3B

Across Experiments 1 and 2, we have demonstrated long-term congruency sequence effects with as many as 160 intervening trials between the first and second presentation of a unique stimulus. However, both experiments used a two-choice flanker task resulting in some feature-overlap between the prime and probe trial. Feature integration accounts have proposed that differences in match between features presented on trial *n*-1 and trial *n* could account for congruency sequence effects by way of event files and a memory retrieval process (Hommel, 1998; Hommel et al., 2001, 2004). This issue will be discussed in greater detail in the General Discussion, however, the goal of Experiment 3 was to test whether the long-term congruency effect would persist when the prime and probe trials consist entirely of nonoverlapping color features.

For both Experiments 3A and 3B, the primary task was the same as Experiments 1 and 2 identifying the color of a central image flanked on the left and right by the same image presented in either the same (congruent) or the alternate color (incongruent). Each image was only presented once as a prime stimulus, and once as a probe stimulus. However, in contrast to Experiments 1 and 2, images could appear in one of four colors (red, blue, green, or yellow). For each participant, colors were randomly assigned to two mutually exclusive color sets. Each prime/probe stimulus pair used both color sets ensuring that colors did not overlap between the prime and probe trial.

Except for the image colors, Experiment 3A followed the same methods as Experiment 1A such that the distance between any given prime and probe stimulus ranged from five to 11 trials (eight trials, on average). Similarly, Experiment 3B followed the same methods as Experiment 2A such that the distance between any given prime and probe stimulus ranged from one to 319 (160 trials, on average).

Method

Participants. All participants were recruited from Amazon Mechanical Turk and compensated \$1.00 for participating. The amount compensated was calculated by estimating the maximum amount of time required to complete each experiment and multiplying by \$6.00 per hour. For each experiment the number of HITs refers to the number of participants who initiated the study and each experiment consisted of unique participants. Participants were included in the study if they completed all trials. For Experiment 3A, 50 HITs were posted, and 50 participants completed all trials. For Experiment 3B, 50 HITs were posted, and 47 participants completed all trials.

Apparatus and stimuli. The apparatus and stimuli were identical to those used in Experiments 1 and 2.

Design. Experiment 3 used a 2 × 2 within-subjects design with prime congruency (congruent vs. incongruent) and probe congruency (congruent vs. incongruent) as factors.

Experiment 3A was constructed using the methods as described in Experiment 1A. Therefore, Experiment 3A consisted of 192 total trials with the distance between each prime and probe stimulus pair ranging from *n*-5 to *n*-11. Experiment 3B was constructed using the methods as described in Experiment 2. Therefore, Experiment 3B consisted of 320 total trials with the distance between each prime and probe stimulus pair ranged from *n*-1 to *n*-319. Each experiment consisted of 50% congruent/incongruent trials, an equal number of each congruency combination between prime/probe pairs (i.e., Con—Con, Con—Inc, Inc—Inc, and Inc—Con). Images were randomly selected for every participant from the total 540 images (Brady et al., 2013) and randomly assigned a color and condition. Each image was only presented twice during the experiment: once in a prime block and once in a probe block.

The colors of the images however, differed from Experiments 1 and 2. For Experiment 3, images could appear in one of four colors: blue, green, red, or yellow. For each participant, the four colors were randomly assigned to two color sets (e.g., blue/green, red/yellow), such that colors in differing sets were never presented together on a single trial (e.g., green/yellow never appeared together). Additionally, each prime/probe pair always consisted of colors from both sets to ensure that colors did not repeat from the prime to probe trial. The assignment of colors to prime/probe trials was counterbalanced for each participant. Therefore, on 50% of trials, Color Set 1 was assigned to the prime stimuli and Color Set 2 to the corresponding probe, and on the other half, Color Set 2 was assigned to the prime and Color Set 1 to the probe.

Procedure. The procedure was identical to Experiments 1 and 2. However, because of the use of four colors, participants were instructed to identify the color of the center image on each trial as quickly and accurately as possible by pressing “b” if the image was blue, “g” if the image was green, “r” if the image was red, and “y” if the image was yellow.

Results

Participants with mean error rates greater than 20% were excluded from the analyses. For Experiment 3A, this eliminated six participants and for 3B this eliminated four participants. For all remaining participants, the RTs from correct trials in each condition were submitted to an outlier removal procedure (the nonrecursive procedure; Van Selst & Jolicoeur, 1994) that eliminated an average of 3.19% and 2.89% of the observations from Experiments 3A and 3B, respectively.

Experiment 3A: *n*-8 trials.

Long-term congruency sequence effects. Mean RTs from correct responses and error rates were submitted to a repeated measures analysis of variance (ANOVA) with prime congruency (congruent vs. incongruent) and probe congruency (congruent vs. incongruent) as factors (see Figure 4 and Table 1). As a result, the two-way interaction between prime congruency and probe congruency was nonsignificant, $F(1, 43) = .86$, $MSE = 2119.31$, $p = .36$, $\eta_p^2 = .02$, showing no differences between the congruency effects when the prime was congruent versus incongruent.

The results of the error analysis also revealed no significant effects of interest. The two-way interaction between prime congruency and probe congruency was nonsignificant, $F(1, 43) = .34$, $MSE = 9.85$, $p = .56$, $\eta_p^2 = .008$.

n-1 congruency sequence effects. Mean RTs from correct responses and mean error rates were submitted to a repeated measures analysis of variance (ANOVA) with trial *n*-1 congruency (congruent vs. incongruent) and trial *n* congruency (congruent vs. incongruent) as within-subject factors (see Figure 4 and Table 2). As a result, the two-way interaction between trial *n*-1 and trial *n* congruency was marginal, though nonsignificant, $F(1, 43) = 3.66$, $MSE = 1882.08$, $p = .06$, $\eta_p^2 = .08$, showing no differences between the congruency effects when trial *n*-1 was congruent versus incongruent.

The results of the error analysis also revealed no significant effects of interest. The two-way interaction between trial *n*-1 congruency and trial *n* congruency was nonsignificant, $F(1, 43) = .68$, $MSE = 4.03$, $p = .41$, $\eta_p^2 = .02$. Average error rates were 2.36%.

Experiment 3B: *n*-160 trials.

Long-term congruency sequence effects. Mean RTs from correct responses and mean error rates from probe trials were submitted to a repeated measures analysis of variance (ANOVA) with prime congruency (congruent vs. incongruent) and probe congruency (congruent vs. incongruent) as factors (see Figure 4

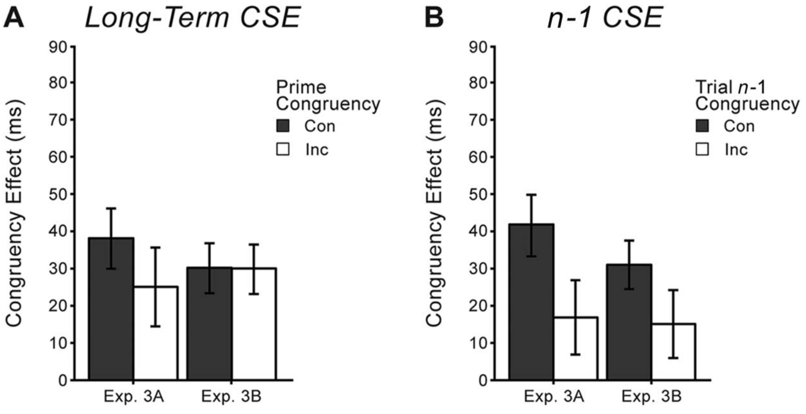

Figure 4. Results of Experiment 3. Figure 4A shows congruency effects in RTs as a function of prime congruency (congruent and incongruent) and experiment (A and B). Figure 4B shows congruency effects in RTs as a function of trial *n*-1 congruency (congruent and incongruent) and experiment (A and B). Error bars represent the standard error of the mean (SEM). In both experiments, the interaction was nonsignificant ($p > .05$).

and Table 1). As a result, the two-way interaction between prime congruency and probe congruency was nonsignificant, $F(1, 42) <$ .01, $MSE = 973.11$, $p = .96$, $\eta_p^2 < .0001$, showing no differences between the congruency effects when the prime was congruent versus incongruent.

The results of the error analysis also revealed no significant effects of interest. The two-way interaction between prime congruency and probe congruency was nonsignificant, $F(1, 42) = .21$, $MSE = 8.48$, $p = .65$, $\eta_p^2 = .005$.

***n-1* congruency sequence effects.** Mean RTs from correct responses and mean error rates were submitted to a repeated measures analysis of variance (ANOVA) with trial *n*-1 congruency (congruent vs. incongruent) and trial *n* congruency (congruent vs. incongruent) as within-subject factors (see Figure 4 and Table 2). As a result, the two-way interaction between trial *n*-1 and trial *n* congruency was nonsignificant, $F(1, 42) = 2.06$, $MSE = 1273.95$, $p = .16$, $\eta_p^2 = .05$, showing no differences between the congruency effects when trial *n*-1 was congruent versus incongruent.

Similarly, the results of the error analysis also revealed no significant effects of interest. The two-way interaction between trial *n*-1 congruency and trial *n* congruency was nonsignificant, $F(1, 42) = .26$, $MSE = 4.28$, $p = .61$, $\eta_p^2 = .006$. Average error rates were 2.58%.

Discussion

The critical result of Experiment 3 was the failure to find long-term congruency sequence effects. Experiment 3, therefore failed to replicate Experiments 1 and 2 when color features did not overlap between prime and probe stimuli. A positive finding would have convincingly ruled out a potential long-term feature integration account of the findings from Experiments 1 and 2. However, the failure to find the effect is more ambiguous. Any theory that relies on memory-retrieval might make the prediction that decreasing the similarity between the prime and probe could diminish or eliminate the effect because the probe is no longer an adequate retrieval cue. Therefore, the finding in Experiment 3 does not provide direct evidence for a long-term feature integration account though it does fail to rule out such a possibility. These issues are discussed in greater detail in the General Discussion.

Stimulus-Response Repetition Analyses

Previous work has demonstrated that stimulus-response repetition biases confounded with congruency manipulations may contribute to, or account entirely for, sequential modulations of congruency effects (e.g., Mayr et al., 2003). This issue will be discussed in more detail in the General Discussion, however to determine the contribution of repetition biases, we compared response repeat to response change trials for both the long-term and *n*-1 congruency sequence effects.

Long-Term Congruency Sequence Effects

Collapsing across Experiments 1 and 2, mean RTs from correct probe trials were submitted to a repeated-measures analysis of variance (ANOVA) with response (repeat vs. change), prime congruency (congruent vs. incongruent), and probe congruency (congruent vs. incongruent) as factors (see Figure 5).

There was a significant main effect of response showing speeded responses for response repeat versus change trials, $F(1, 190) = 40.25$, $MSE = 3536.39$, $p < .0001$, $\eta_p^2 = .17$. The two-way interaction between prime congruency and probe congruency was also significant showing a smaller congruency effect when the prime trial was incongruent as compared with congruent, $F(1, 190) = 16.09$, $MSE = 2582.77$, $p < .0001$, $\eta_p^2 = .08$. Critically, three-way interaction between response, prime congruency, and probe congruency was nonsignificant, $F(1, 190) = .14$, $MSE = 1717.33$, $p = .71$, $\eta_p^2 < .001$.

Therefore, although we found an overall long-term response priming effect, we found no significant difference between the long-term congruency sequence effects for response repeat versus change trials.

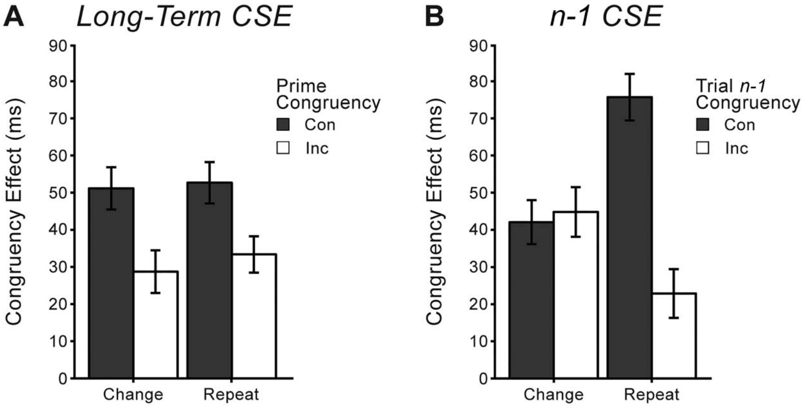

Figure 5. Results of the stimulus-response repetition analyses. Figure 5A shows congruency effects in RTs collapsed across all experiments as a function of prime congruency (congruent and incongruent) and response (change and repeat). Figure 5B shows congruency effects in RTs collapsed across all experiments as a function of trial *n*-1 congruency (congruent and incongruent) and response (change and repeat). Error bars represent the standard error of the mean (SEM).

n-1 Congruency Sequence Effects

Collapsing across Experiments 1 and 2, mean RTs from correct trials were submitted to a repeated measures analysis of variance (ANOVA) with response (repeat vs. change), trial *n*-1 congruency (congruent vs. incongruent), and trial *n* congruency (congruent vs. incongruent) as factors (see Figure 5). One participant was removed prior to the analysis due to missing data in one condition.

There was a significant main effect of response showing speeded responses for response repeat versus change trials, $F(1, 189) = 28.66$, $MSE = 3892.71$, $p < .0001$, $\eta_p^2 = .13$. The two-way interaction between trial *n*-1 congruency and trial *n* congruency was significant showing a smaller congruency effect when the prime trial was incongruent as compared with congruent, $F(1, 189) = 28.99$, $MSE = 2055.37$, $p < .0001$, $\eta_p^2 = .13$. However, the critical three-way interaction between response, trial *n*-1 congruency, and trial *n* congruency was also significant, $F(1, 189) = 42.15$, $MSE = 1741.5$, $p < .0001$, $\eta_p^2 = .18$.

To probe the three-way interaction, the response change and repeat trials were analyzed separately. The analysis of the change trials revealed no significant interaction between trial *n*-1 congruency and trial *n* congruency, $F(1, 189) = .18$, $MSE = 1953.09$, $p = .67$, $\eta_p^2 = .001$. However, the analysis of the repeat trials revealed a significant interaction with a smaller congruency effect when trial *n*-1 was incongruent as compared to congruent, $F(1, 189) = 71.94$, $MSE = 1843.78$, $p < .0001$, $\eta_p^2 = .28$. Therefore, the *n*-1 congruency sequence effect was only found for response repeat and not for response change trials.

Short- and Long-Term Comparison Analysis

The results thus far suggest that the short- and long-term congruency effects are the result of independent processes. However, to directly test their independence, we analyzed the congruency effects on probe trials as a function of the previous trial congruency. We collapsed across Experiments 1 and 2 and submitted the mean RTs from correct probe trials to a repeated-measures analysis of variance (ANOVA) with prime congruency (congruent vs. incongruent), trial *n*-1 congruency (congruent vs. incongruent), and trial *n* (probe) congruency (congruent vs. incongruent) as factors. Two participants were removed prior to the analysis due to missing data.

The critical three-way interaction, was nonsignificant, $F(1, 188) = 1.55$, $MSE = 4320.43$, $p = .21$, $\eta_p^2 = .003$. Furthermore, the two-way interaction between trial *n*-1 and trial *n* (probe) congruency was significant, $F(1, 188) = 8.64$, $MSE = 4566.08$ $p = .004$, $\eta_p^2 = .04$, and the two-way interaction between prime and trial *n* (probe) congruency was also significant, $F(1, 188) = 6.62$, $MSE = 3742.42$ $p = .01$, $\eta_p^2 = .03$. Therefore, the presence of the long-term congruency sequence effect did not depend on the previous trial congruency.

General Discussion

The current study investigated whether congruency sequence effects could be observed on a long-term basis. Across Experiments 1 and 2, congruency effects were significantly smaller on probe trials when the prime was incongruent versus congruent. Long-term congruency sequence effects were demonstrated with an average of eight intervening trials (Experiment 1), and 160 intervening trials (Experiment 2); and were observed in both response-repeat and response-change trials. In Experiment 3, when specific colors assigned to prime stimuli were not repeated when presented as probes, we failed to find long-term congruency sequence effects.

In addition to the long-term congruency sequence effect, we also found the traditional *n*-1 congruency sequence effect. However, the *n*-1 sequence effect was only observed in experiments including a high-conflict manipulation. Last, the *n*-1 congruency sequence effect was only found for response repeat trials and not for response change trials, suggesting that these effects could be explained entirely by stimulus-response repetitions.

The finding that a single presentation of a unique stimulus can influence performance on the second, much later presentation, is consistent with the instance-based memory account. Per this account, the attentional priorities adopted in the presence of unique stimulus features on the prime trial were retrieved and reinstated when those features were presented again. This work contributes to a small, but growing body of evidence suggesting that adjustments in cognitive control processes like attention can be guided by memory representations (Awh et al., 2012; Egner, 2014; Hutchinson & Turk-Browne, 2012). Memory influences on cognitive control have largely been studied in the context of negative priming (D'Angelo et al., 2016; Frings et al., 2015) and visual spatial attention using visual search tasks (e.g., Chun & Jiang, 1998, 2003; Hutchinson & Turk-Browne, 2012). Our findings complement and extend this prior work demonstrating long-term memory can influence selective attention in a conflict task.

Although the instance-based memory account provides one explanation for the current results, we now discuss other accounts of the congruency sequence and proportion congruent effects and the implication of our findings. Whether modulations of congruency effects indexes adjustments in cognitive control or instead, emerges from lower level learning and memory processes, remains one major point of disagreement. We have organized our discussion around these two perspectives.

Control Perspectives

Expectation and voluntary control accounts. The expectation account postulates that participants develop expectations about the congruency of upcoming trials and engage in compensatory voluntary control strategies (Gratton et al., 1992; Logan & Zbrodoff, 1979). For example, the *n*-1 congruency sequence effect could reflect deliberate controlled adjustments following participants' expectation that trial *n* will be the same congruency as trial *n*-1 (Gratton et al., 1992). In proportion congruent designs, participants could become aware that the trials are mostly congruent or mostly incongruent and then engage in global control strategies in anticipation of the more likely item type (Logan & Zbrodoff, 1979).

It is possible that setting voluntary attentional priorities could explain the long-term congruency effect. For example, when a stimulus is presented, participants might expect the stimulus will repeat and prepare a strategy for the next time they see that stimulus. When that stimulus is presented a second time, they would then voluntarily adopt the prepared strategy. However, this proposal relies on several assumptions that make such an explanation unlikely.

First, we must assume participants had become aware that each prime stimulus would be repeated as a probe. Although awareness was not measured in the current experiments, participants in Experiment 1 could easily have noticed that primes are repeated as probes every five to 11 trials. However, in Experiment 2 all the prime trials were presented first, followed by all the probe trials. Therefore, during the prime block, participants have no reason to expect stimulus repetition, and during the probe block, once stimuli start repeating, it would be too late to rely on previously unprepared stimulus-specific voluntary strategies. Second, participants would have to actively maintain multiple stimulus-specific strategies simultaneously. In Experiment 1, they would have to maintain five to 11 at any given point and in Experiment 2 they would need to maintain 160. Although it is unknown how many stimulus- or context-specific voluntary strategies can be maintained simultaneously, 160 seems implausible. Finally, participants would have to rapidly adjust attentional control in a voluntary manner at the time of stimulus onset. However, voluntary control is traditionally thought of as slow and effortful (Shiffrin & Schneider, 1977). Taken together, the expectation or voluntary control account is not a viable explanation of the long-term congruency sequence effects.

Conflict-monitoring accounts. According to the conflict-monitoring model, modulations of congruency effects reflect conflict-driven adjustments in cognitive control (Botvinick et al., 2001). That is, the detection of response-conflict—the simultaneous activation of competing responses—triggers an up-regulation of cognitive control which biases attentional priority toward the target dimension and away from the distractor dimension. Thus, the influence of the distractor dimension is reduced following a high-conflict, incongruent trial producing the congruency sequence effect.

The conflict-monitoring model and many of its variants (e.g., Botvinick, 2007; Braver, 2012; Dreisbach & Fischer, 2012; Egner, 2008; Hazeltine, Lightman, Schwarb, & Schumacher, 2011; Jiang et al., 2014) are incapable of explaining the long-term congruency effects for the same reasons that they have difficulties explaining item- and context-specific proportion congruent effects. Namely, adjustments in control operate on task-level representations, prespecified by the model as relevant versus irrelevant. For example, in a Stroop task, the detection of conflict would trigger an attentional bias toward the task-relevant dimension of color, regardless of the item presented. Of course, item- and context-specific proportion congruent effects, and now the long-term congruency sequence effect, demonstrate that control can be adjusted differentially for specific items. Traditional conflict-monitoring models cannot discriminate between items while detecting conflict or adjusting control, and therefore, cannot produce item-specific effects.

The adaptation-by-binding account proposes one remedy: aggregate conflict-driven learning at the level of item features (Blais et al., 2007; Verguts & Notebaert, 2008, 2009). Like other conflict-monitoring accounts, the detection of response conflict provides a signal that task-relevant connections should be strengthened. In contrast to the previous models, however, this is accomplished through a Hebbian learning rule that only strengthens connections between active representations. Representations consist of item-level features (e.g., the color red, the word "BLUE"), and considered active if they are task-relevant and currently presented. Therefore, item-specific features can selectively become associated to the current task representation if it is frequently paired with conflict. Such computational models have been successful in simulating item-specific proportion congruent effects as well as more generalized forms of the congruency sequence effects (Blais et al., 2007; Verguts & Notebaert, 2008, 2009).

The adaptation-by-binding account may be able to produce the long-term congruency sequence effects, but doing so may stretch the model beyond its plausible limits. For example, it is not clear whether the model could produce single-trial, long-term learning, or whether repeated presentations are required to produce measurable changes in performance. Additionally, the irrelevant contextual features that defined the unique stimuli would need to be considered "task-relevant" by the model for them to be active during learning. Each unique stimulus would also need to receive its own input layer in which case the model would require at most 160 input layers. The stimulus-set is never specified prior to the experiment so we would also have to assume that each new stimulus presented creates the new required input layers. If we accept these assumptions, it is possible that the model could produce the long-term congruency sequence effects. However, it is not clear that this model is compatible with these assumptions. Furthermore, once these additional assumptions are made, it is not clear how different this account is from the instance-based memory account.

Conflict-monitoring with memory selection. We propose a new alternative conflict-monitoring model that could account for the long-term congruency sequence effect. The congruency task literature has had difficulty explaining why cognitive control adjustments have been demonstrated to be at times, specific, failing to generalize (e.g., item-specific), and at other times, nonspecific, successfully generalizing across stimuli (for reviews, see Abrahamse et al., 2016; Braem et al., 2014; Egner, 2014). The conflict-monitor, as specified by traditional accounts (Botvinick et al., 2001; Braver, 2012) can detect response conflict and aggregate recent or frequent conflict within a conflict-signal, but lacks the ability to select what experiences are aggregated or the ability to preserve multiple conflict signals. To incorporate the ability to select and store multiple conflict signals into the conflict monitor is problematic because it would require the monitor to know in advance, what items should be aggregated over and which signals preserved (e.g., Egner, 2008).

Instead, we suggest a memory-retrieval process could provide a mechanism by which prior experiences are selected and then aggregated over by a conflict-monitor. For example, the word "RED" in blue ink, would cue the retrieval of any other similar experiences: any trial containing the word "RED" or the color blue. The conflict-monitor then detects and aggregates the conflict across the retrieved item-set and adjusts control accordingly. By offloading the selection to a memory system, the conflict-monitor does not need to distinguish between items and can bias attentional priority along task-dimensions, as originally specified (Botvinick et al., 2001). However, by allowing memory to select what prior experiences are evaluated by the conflict-monitor, the model becomes extremely flexible in determining when control should be adjusted.

Such an account, for example, can easily explain item- and context-specific proportion congruent effects. In a typical item-specific design (e.g., Jacoby et al., 2003), items are organized into two distinct sets associated with different proportions of congruency (e.g., the words "RED" and "BLUE" could be high proportion congruent, and the words "GREEN" and "YELLOW" could be low proportion congruent). Importantly, the individual features do not overlap between item sets (though, see Bugg & Hutchison, 2013; Bugg, Jacoby, & Chanani, 2011). For example, if the word "RED" is the high proportion item set and the word "GREEN" in the low proportion, then the word and/or color red will never be presented with the word and/or color green. Presenting "RED" in blue will then only cue the retrieval of items from the high proportion item set. Similarly, items that appear in one context will be associated to items that have also appeared in that context by virtue of their shared contextual features (e.g., same location). Therefore, context-specific effects (Crump et al., 2006), including generalization to frequency unbiased items (Crump et al., 2017; Crump & Milliken, 2009; Weidler & Bugg, 2016) would also be predicted by such an account. Similarly, memory retrieval could contribute to traditional congruency sequence effects if we accept that that more recent memories are more easily retrievable than distant memories (e.g., Egner, 2014).

There are, however, some potential remaining issues. For example, memory-based theories beg questions about the active features and/or dimensions controlling memory retrieval. Prior work in the item-specific proportion congruent literature has suggested that single features, rather than conjunctions of features, drive proportion congruent effects (e.g., Bugg & Hutchison, 2013; Jacoby et al., 2003). Similarly, context-specific transfer effects suggest that single, context-features can also drive memory retrieval (e.g., Crump et al., 2017; Crump & Milliken, 2009; Weidler & Bugg, 2016). In the current study, we found long-term congruency sequence effects when stimuli shared contextual features. We only found this effect, however, when stimuli appeared in the same color set (Experiments 1 and 2). When the prime and probe appeared in different colors (Experiment 3) we failed to find evidence for the long-term congruency effect. These findings suggest that the conjunction of features may have served as a retrieval cue in the current study. A task for future work is to clarify the conditions that enable a feature or conjunction of features to drive retrieval.

Noncontrol Perspectives

Although the control perspective remains popular, several accounts have challenged the underlying premise that modulations of the congruency effect index cognitive control adjustments. Instead, some have argued that learning and memory processes could produce the same effects without the need for notions of conflict-driven control (Mayr et al., 2003; Schmidt, 2013; Schmidt & Besner, 2008). For example, many congruency task designs contain item- or feature-repetition biases that are confounded with congruency manipulations. These confounds have produced alternative explanations of congruency phenomena, two of which are of importance to the current study.

Contingency learning. First, the contingency learning account suggests that the frequency of item presentation can produce predictive relationships between item features and responses. Responses are thought to be speeded for stimuli that contain features that are highly predictive of a response regardless of congruency. For example, if the word "BLUE" is most often presented in red ink, then the word "BLUE" becomes predictive of the red response, and responses would be quicker relative to nonpredictive items. In many proportion congruent designs, the frequency of item presentation is confounded with the proportion congruent manipulations. Therefore, the contingency learning account has been sufficient for explaining many proportion congruent effects, although still unable to explain transfer to frequency unbiased items (Crump et al., 2017; Weidler & Bugg, 2016). In the current study, however, we used a two-choice flanker task and all potential contingencies were held constant. That is, there were no predictive relationships between stimulus features and responses that could explain our results.

Stimulus-specific repetition priming and feature integration. The stimulus-specific repetition priming account was proposed to explain congruency sequence effects. Mayr, Awh, and Laurey (2003) noted that the frequency of complete stimulus-response repetitions in trial-to-trial transitions are unbalanced in two-choice congruency tasks. Specifically, some congruent-to-congruent and incongruent-to-incongruent transitions contain complete stimulus-response repetitions which could speed responses selectively for those conditions (Hommel, 1998; Pashler & Baylis, 1991). Consistent with this proposition, Mayr et al. (2003) found that the congruency sequence effect disappeared when response repetition trials were either removed from the analysis, or prevented from occurring in the trial sequence. However, many studies have now demonstrated congruency sequence effects while controlling for stimulus-response repetitions suggesting stimulus-response repetitions cannot entirely account for sequential effects (Akçay & Hazeltine, 2007; Kerns et al., 2004; Kunde & Wühr, 2006; Ullsperger, Bylsma, & Botvinick, 2005; Weissman, Jiang, & Egner, 2014).

To determine whether stimulus-response repetitions played a role in producing the current result we compared response repeat with response change trials. We found an overall long-term response repetition effect, in that performance was facilitated when responses repeated from prime to probe trials. However, the size of the long-term congruency sequence effect did not differ between response repeat and change trials suggesting that the current result could not be explained by stimulus-response repetitions.

The feature integration account makes a similar proposal. According to this account, stimuli and responses that co-occur in time are bound together in a common episodic memory representation called an event file (Hommel, 1998; Hommel et al., 2001, 2004); a more general form of the "object file" proposed by Kahneman, Treisman, and Gibbs (1992). The subsequent reoccurrence of any features automatically retrieves the entire event file which could either help or hinder performance depending on the match between the currently presented features and the features contained in the event file. Across two consecutive trials, features are either completely matched, partially matched, or completely mismatched. Critically, an effortful "unbinding" process is necessary whenever features are partially matched. That is, feature representations must be unbound from the associated event file so that they can be reused in the creation of a new event file. Therefore, performance would be predicted to be slowed on partial match trials relative to complete match or complete mismatch trials. In many congruency task designs, feature overlap is confounded with congruency sequences and as such, feature integration can explain trial-to-trial effects in many cases (for reviews, see Egner, 2007, 2014). Similarly, Experiments 1 and 2, we utilized a two-choice flanker task that contains these same feature overlap confounds.

Event files are typically referred to as "transient" or "temporary" memory structures (Hommel, 1998; Hommel et al., 2001, 2004), and are generally invoked to explain short-term, trial-to-trial effects (Egner, 2007, 2014). However, event files are based on instance-based memory theories (Hintzman, 1986; Logan, 1988, 1990), and typically, the timescale is not explicitly defined. If we assume that event files are stable episodic memory structures, then feature integration, like the other memory-retrieval accounts proposed above, could also explain long-term congruency sequence effects. The evidence for long-term feature integration across our experiments, however, is mixed and largely inconclusive.

On the one hand, across Experiments 1 and 2 we found long-term congruency sequence effects for response-change trials. This result is generally inconsistent with feature integration theories. One possibility, as others have suggested, is that event files may not be limited to stimulus–response associations. That is, other aspects of an experience like perceived conflict and control processes may also be encoded in the event file (Bugg & Hutchison, 2013; Spapé & Hommel, 2008). We could speculate that the added contextual features could have provided additional support for event file retrieval, even in the absence of response repetitions (for a similar proposal, see Spapé & Hommel, 2008), or perhaps response outcomes are forgotten more rapidly than degree of conflict. On the other hand, in Experiment 3 we failed to find long-term congruency sequence effects when colors did not repeat from prime to probe trials. This result is consistent with feature integration theory. Although our speculation about why we found long-term effects in response-change trials could have also applied here, so these two results are at odds. Furthermore, any memory-based explanation might predict that altering the similarity between the prime and probe trials would influence the long-term effects. Therefore, the failure to find long-term effects when colors do not repeat, does not allow us to discriminate between any of the memory-based theories we have proposed. Finally, to the extent that you allow event files to be permanent memory representations and allow them to encode many aspects of our experience like stimulus and context features, responses, perceived conflict, and control processing, it is not clear how different feature integration theories are from instance-based memory theories.

Perceptual learning and attentional control. Finally, we propose an alternative noncontrol account. Perceptual learning refers to experience-dependent changes in perception and is thought to reflect perceptual or neural plasticity in visual representations (Goldstone, 1998; Lu, Hua, Huang, Zhou, & Dosher, 2011; Roelfsema, van Ooyen, & Watanabe, 2010; Sasaki, Nanez, & Watanabe, 2010). Perceptual learning has been demonstrated across a wide variety of perceptual tasks including the discrimination and detection of stimulus orientation (Dosher & Lu, 1998; Shiu & Pashler, 1992; Vogels & Orban, 1985), motion direction (Ball & Sekuler, 1987; Ball, Sekuler, & Machamer, 1983), and object recognition (Furmanski & Engel, 2000), to name a few (for a review, see Watanabe & Sasaki, 2015). Importantly, across tasks, selective attention has been shown to influence perceptual learning, such that learning is enhanced for task-relevant, or attended features as compared with irrelevant, unattended features (Ahissar & Hochstein, 1993; Gutnisky, Hansen, Iliescu, & Dragoi, 2009; Shiu & Pashler, 1992; Szpiro & Carrasco, 2015).

One possible explanation of the long-term congruency sequence effect is that selective attention influences perceptual learning on the first presentation, which in-turn, influences how the stimulus is attended on the second presentation. For example, when presented with an incongruent stimulus, attention is shifted toward the target and away from the flankers facilitating perceptual learning of the target features relative to the flanker features. On the second presentation, the altered visual representation and enhanced perceptual processing of the target could cue attention toward the target, facilitating performance if the second presentation is incongruent.

There is some evidence that increased selective attention demands from incongruent stimuli may enhance target representations on a long-term basis. As noted earlier, in perceptual learning tasks, learning is enhanced for attended versus unattended features (Ahissar & Hochstein, 1993; Gutnisky et al., 2009; Shiu & Pashler, 1992; Szpiro & Carrasco, 2015). However, recognition memory has also been shown to be improved for items previously presented with incongruent versus congruent distractors. Here, the increased need for cognitive control is thought to facilitate target encoding at the time of study improving later memory recognition (Krebs, Boehler, De Belder, & Egner, 2015; Rosner, D'Angelo, MacLellan, & Milliken, 2015; Rosner & Milliken, 2015).

Perceptual learning could provide an important mechanism for informing how attention changes through experience and learning. Perceptual learning has been shown to be highly stimulus-specific and produces long-lasting effects (Watanabe & Sasaki, 2015). Though in contrast to the immediate effects in our study, measuring changes in performance on perception tasks often requires extensive training (Dosher & Lu, 1999). Therefore, changes in perception alone could not account for the current results. Instead, we are suggesting that small changes in perceptual representations could help guide attention, causing more immediate and measurable effects in attention tasks.

Short- and Long-Term Congruency Sequence Effects: Single or Multiple Processes?

In the current experiments, we found both short- (*n*-1) and long-term congruency sequence effects. All current accounts of the short-term congruency sequence effects posit rapidly decaying representations and are generally incapable of accounting for the long-term congruency sequence effects (Egner, 2007). The alternative accounts we have proposed above however, could accommodate both long- and short-term effects. For example, if memory retrieval mediates shifts in attentional control then we might expect that similarity in temporal context could cue retrieval (e.g., Egner, 2014). One possibility is that both short- and long-term effects are produced via a single, memory-driven process. Alternatively, we might speculate the contribution from two independent processes: a memory-driven process and a short-term, conflict-driven process.

On the one hand, there were some clear differences between the short- and long-term effects found in the current study. First, the long-term effects were insensitive to increased response conflict, whereas the short-term effects were only present in the high conflict experiments. This might be expected, if we assume that the short-term effect reflects changes in the conflict-signal which dissipates over time (e.g., Botvinick et al., 2001). Second, the long-term effects were present for both response change and response repeat trials while the short-term effects were only present for response repeat trials. As such, the short-term effect could be explained entirely by stimulus-response repetitions (e.g., Mayr et al., 2003), while the long-term effect cannot. Third, and most importantly, we found no interaction between the short- and long-term effects. Taken together, these differences suggest that the two phenomena measured in the current study do not reflect the same underlying process.

On the other hand, several other studies have reported *n*-1 congruency sequence effects while controlling for repetition biases (e.g., Kunde & Wühr, 2006; Weissman et al., 2014), and others have found *n*-1 congruency sequence effects to be insensitive to changes in the degree of conflict (e.g., Weissman & Carp, 2013). One possible resolution to these inconsistencies, is that a memory-driven process can, under the right circumstances, contribute to short-term congruency effects. That is, if the stimuli presented on trial *n* provides an effect retrieval cue for trial *n*-1, then we might expect that a memory-driven process could influence performance on trial n. Of course, if trial *n* is a poor retrieval cue for trial *n*-1, then we might expect no influence from the memory-retrieval process, leaving only the short-term, conflict-driven effect. In the current study, we alternated the context trial-to-trial such that the same contextual cue never repeated from trial *n*-1 to trial *n*. Therefore, it could be the case that trial *n*, while an effective retrieval cue for the prime trial (e.g., *n*-8, *n*-160), was a poor retrieval cue for trial *n*-1. As such, the short-term effects observed in the current study reflect only the influence of a short-term, conflict-driven process, which was sensitive to the degree of conflict, and response repetition.

Consistent with this interpretation, Spapé and Hommel (2008) found that the *n*-1 congruency sequence effect was eliminated on trials that alternated contextual cues, but preserved when contextual cues repeated. The authors suggested that the alternation of contextual cues selectively disrupted episodic retrieval on those trials. However, others have found *n*-1 congruency sequence effects with nonrepeating contextual cues (Egner et al., 2010; King et al., 2012). One possibility is that the combination of making a single prior experience (the prime trial) distinctly similar to trial *n* and the nonrepeating contextual cues, could have disrupted memory retrieval of the *n*-1 trial. This would also suggest that memory retrieval in this context, is a competitive process, whereby only the most similar experiences are retrieved. What constitutes an effective versus ineffective retrieval cue, however, remains unclear. Furthermore, whether only a single, most-similar previous experience is retrieved, or if a collection of similar experiences is aggregated over and used to guide attention remains an open question.

Broader Implications

A global aim of this research program is to determine how memory for specific prior experiences guides performance in the present moment. Previous work has focused on evidence that contextual cues can rapidly modify cognitive control settings. The instance-based memory account of contextual control (Crump, 2016) is the general hypothesis that memory not only preserves a record of the details of specific experiences (Hintzman, 1986; Jacoby & Brooks, 1984; Logan, 1988), but also preserves a record of the control procedures involved in processing those experiences (Kolers & Roediger, 1984). Our aim here was to supply evidence showing that attentional control in the present moment can be modified on a long-term basis by memories of specific prior processing experiences. Beyond the implications of this finding for theories of cognitive control from the congruency literature, we are optimistic the idea behind our results will spur more work into the memorial basis of cognitive control. In everyday life, we expect that memory for prior cognitive control operations routinely optimizes performance in familiar environments. In these situations, people gain the benefit of applying memory-based procedures for regulating information without the normal cost of effortful deliberation. We also expect that problems in regulating the flow of information can result from the inappropriate use of, or failure to rely on memory. For example, deliberate control may need to override memory-based control when situations act as strong cues for prior memory procedures that may not be appropriate for the present moment. Or, when memory fails to encode or retrieve cognitive control procedures, people may be forced to rely on taxing voluntary control processes to supply the control they normally receive from memory for free. The present results show that some aspects of the attentional control procedures used during a fleeting encounter with a unique stimulus in a flanker task have long-term influences on responding to that stimulus in the future. Everyday life presents many more fleeting and meaningful experiences, and the capacity of memory to preserve and reinstate past control procedures to regulate cognition, behavior, and performance points to a healthy avenue for future work.

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