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Contingent attentional capture triggers the congruency sequence effect☆

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ABSTRACT

The congruency effect in distracter interference tasks is often reduced after incongruent as compared to congruent trials. Here, we investigated whether this congruency sequence effect (CSE) is triggered by (a) attentional adaptation resulting from perceptual conflict or (b) contingent attentional capture arising from distracters that possess target-defining perceptual features. To distinguish between these hypotheses, we varied the perceptual format in which a distracter (word or arrow) and a subsequent target (word or arrow) appeared in a prime-probe task. In Experiment 1, we varied these formats across four blocks of a factorial design, such that targets always appeared in a single perceptual format. Consistent with both hypotheses, we observed a CSE only when the distracter appeared in the same perceptual format as the target. In Experiment 2, we varied these formats randomly across trials within each block, such that targets appeared randomly in either format. Consistent with the attentional capture account but inconsistent with the perceptual conflict account, we observed equivalent CSEs in the same and different perceptual format conditions. These findings show for the first time that contingent attentional capture plays an important role in triggering the CSE.

1. Introduction

Humans are notoriously distractible. A prototypical example from the laboratory comes from the Stroop task (Stroop, 1935), wherein people are instructed to identify the color in which a word is printed. Although the word's identity is irrelevant, participants respond more slowly when the word is incongruent with the print color (e.g., BLUE printed in red ink) as compared to congruent (e.g., GREEN printed in green ink). Analogous *congruency effects* have been observed in a variety of other distracter interference tasks including the flanker task (Eriksen & Eriksen, 1974), the Simon task (Simon & Rudell, 1967), and the prime-probe task (Neumann & Klotz, 1994). The ubiquity of such effects indicates that selective attention usually fails to eliminate the influence of distracters on performance.

Some researchers have argued, however, that the degree to which selective attention minimizes the influence of distracters on performance varies with the nature of distraction on the previous trial. Consistent with this view, the congruency effect in distracter interference tasks is smaller after incongruent as compared to congruent trials (Gratton, Coles, & Donchin, 1992). This *congruency sequence effect* (CSE) is often attributed to attentional control processes that (a) enhance the processing of relevant stimuli and/or responses and/or (b) reduce the processing of irrelevant stimuli and/or responses when the previous trial was incongruent as compared to congruent (e.g., Botvinick, Braver, Barch, Carter, & Cohen, 2001). While some have argued that highly-prevalent feature integration and contingency learning confounds are the true source of the CSE in many paradigms (Hommel, Proctor, & Vu, 2004; Mayr, Awh, & Laurey, 2003; Mordkoff, 2012; Schmidt & De Houwer, 2011), CSEs remain robust in some tasks even after removing these confounds (Kim & Cho, 2014; Kunde & Wühr, 2006; Schmidt & Weissman, 2014; Weissman, Egner, Hawks, & Link, 2015; Weissman, Jiang, & Egner, 2014).

What distinguishes tasks that engender a CSE in the absence of the typical confounds from those that do not? One factor is whether the distracter is processed before the target, such that it can activate a response before the target does (Weissman et al., 2014). For example, the CSE is highly robust in the prime-probe task, wherein the distracter precedes the target (Schmidt & Weissman, 2014; Weissman et al., 2015). A second factor is whether the distracter appears at the location of an upcoming target, such that it cannot be filtered by spatial attention (Weissman et al., 2014). In the present study, we investigated a third potential factor, which is whether the distracter is perceptually similar to a potential target. Consistent with this possibility, the distracters that engendered "confound-minimized" CSEs in recent studies of the prime-probe task possessed target-defining shapes and colors (Kunde & Wühr, 2006; Schmidt & Weissman, 2014; Weissman et al., 2014, 2015). For instance, the words "Left," "Right," "Up," and "Down" were used as both target and distracter stimuli in Schmidt and Weissman

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(2014, Experiment 2). Thus, each distracter (e.g., "Left") looked like a potential target.

There are at least two reasons why the CSE might be larger when distracters are more versus less visually similar to targets in the prime-probe task. First, *perceptual conflict* might serve as a signal to attentional adjustment. For instance, perceiving visually-mismatching distracter and target stimuli on a previous incongruent trial (e.g., "Left" priming "Right") might lead to a narrowing of attention toward the target on the following trial. Thus, smaller congruency effects would be expected relative to when the target and distracter matched on the previous trial (e.g., "Left" priming "Left"). In this account, a CSE would not be observed if distracters and targets were presented in different perceptual formats (e.g., words and arrows), because both congruent stimuli (e.g., "Left" priming an arrow pointing to the left) and incongruent stimuli (e.g., "Left" priming an arrow pointing to the right) are visually mismatching and therefore induce equivalent perceptual conflict.

Second, *attentional set* might be an important determinant of the CSE. A distracter that possesses a target-defining perceptual feature involuntarily attracts attention (e.g., Chun & Jiang, 1998; Cosman & Vecera, 2014; Moore & Weissman, 2010; Serences et al., 2005; Thomson, Willoughby, & Milliken, 2014). Critically, this phenomenon, known as contingent attentional capture, could enhance the CSE in any of several ways. First, it could raise the probability that the distracter is translated into a response before the target, thereby allowing control processes to better modulate (e.g., suppress) that response before the target response reaches threshold (e.g., Ridderinkhof, 2002). Second, it could increase the size of the congruency effect, which is the primary determinant of CSE magnitude in some accounts (e.g., Botvinick et al., 2001; Dreisbach & Fischer, 2012). Third, it could aid the formation of a memory about whether the previous trial was congruent or incongruent, which control processes might employ to modulate distracter and/or target processing in the current trial (Egner, 2014; Gratton et al., 1992). The goal of the present study was not to distinguish among these and other mechanisms by which contingent attentional capture might trigger the CSE. It was merely to establish whether such capture is necessary to trigger the CSE. Thus, for now, we refer to these mechanisms collectively as the attentional capture hypothesis.

As explained above, both the *perceptual conflict* and *attention capture* accounts would suggest that the CSE should be larger when the perceptual features of distracters match those of potential targets than when they do not. Experiment 1 tests this hypothesis, and Experiment 2 attempts to distinguish between these two alternative perspectives.

2. Experiment 1

To investigate whether the perceptual similarity of distracter and target stimuli impacts the magnitude of the CSE, we asked participants to perform a variant of the prime-probe tasks employed by Schmidt and Weissman (2014). In each trial, a distracter preceded a target that participants were asked to identify. Specifically, participants indicated which of four possible directions – left, right, up, or down – was indicated by the target by making a spatially-compatible response. Critically, in each trial the distracter and the target appeared in one of two perceptual formats: a word format ("Left," "Right," "Up," or "Down") or an arrow format ("<," ">," "∧," or "∨"). The four possible combinations of distracter format and target format were presented in four separate blocks. As we noted earlier, both the perceptual conflict and attentional capture hypotheses predicted that the CSE would be larger in blocks wherein the distracter and target formats matched than in blocks wherein these formats mismatched.

2.1. Method

2.1.1. Participants

Twenty-four Ghent University undergraduates participated in Experiment 1 in exchange for €5.

2.1.2. Apparatus

Stimulus and response timing were controlled by E-Prime 2 (Psychology Software Tools, Sharpsburg, PA). Participants responded to left words and left arrows with the "F" key using the left middle finger, to right words and right arrows with the "G" key using the left index finger, to up words and up arrows with the "J" key using the right middle finger, and to down words and down arrows with the "N" key using the right index finger. The study was conducted using a PC laptop equipped with an AZERTY keyboard and a 15″ monitor.

2.1.3. Materials and design

The stimuli were presented in white, bold Courier New font on a black screen and consisted of four arrow stimuli (<, >, ∧, and ∨) and four Dutch direction words (Links [Left], Rechts [Right], Boven [Up], and Beneden [Down]). Distracter and target arrows, respectively, were presented in 36 and 18 point fonts. Analogously, distracter words and target words, respectively, were presented in 20 and 10 point fonts. Thus, distracters were always twice as large as targets. Note that arrows were presented in larger fonts than words to roughly equate the subjective size of these stimuli. Indeed, when presented in the same font size, single character arrows take up much less horizontal space than multiple character words.

As in our other recent studies (Schmidt & Weissman, 2014; Weissman et al., 2014, 2015), we employed the following procedures to avoid feature integration and contingency learning confounds that are often confounded with the CSE. To prevent feature integration confounds, which are induced by repeating stimuli and/or responses across adjacent trials, we alternated between a "Left–Right" task (odd trials), which involved left and right arrows and words, and an "Up–Down" task (even trials), which involved up and down arrows and words. In each task, there were two congruent distracter-target pairings ("Left–Right" task: Left–Left & Right–Right; "Up–Down" task: Up–Up & Down–Down) and two incongruent pairings ("Left–Right" task: Left–Right & Right–Left; "Up–Down" task: Up–Down & Down–Up). As noted earlier, participants responded with different fingers in the two tasks. Thus, our design precluded all stimulus and response repetitions and, hence, feature integration confounds. To prevent contingency learning biases, which occur when each congruent distracter-target pairing is presented more often than each incongruent distracter-target pairing, we presented the congruent and incongruent distracter-target pairings in each task approximately equally often (trials were selected randomly with replacement).

2.1.4. Procedure

The four combinations of distracter perceptual format (word, arrow) and target perceptual format (word, arrow) were presented in four 120-trial blocks. We presented these blocks in four orders that were counterbalanced across participants: (1) arrow–arrow, word–arrow, word–word, arrow–word; (2) word–arrow, arrow–arrow, arrow–word, word–word; (3) word–word, arrow–word, arrow–arrow, word–arrow; and (4) arrow–word, word–word, word–arrow, arrow–arrow. An instruction screen appeared at the beginning of each block.

Each trial consisted of several sequential events. To begin, there was a distracter (133 ms), a blank screen (33 ms), the target (133 ms), and a second blank screen (1367 ms, or until a response was made). Correct responses were followed by another 500 ms blank screen. Incorrect responses and trials in which participants failed to respond within 1367 ms were followed by a red "X" for 1500 ms. All stimuli appeared at the center of the screen.

2.1.5. Data analysis

Mean response times (RTs) for correct trials and mean percentage error rates were assessed in each of the four blocks. Trials following errors were removed, as was the first trial of each block. One participant was excluded for performing with less than 70% accuracy in one block. Indeed, this participant responded incorrectly in all incongruent trials of this block, indicating that he/she responded to the distracter rather than to the target.

We analyzed the mean RT and mean error rate data with separate repeated-measures ANOVAs, each of which contained four factors: current congruency (congruent, incongruent), previous congruency (congruent, incongruent), distracter-target similarity (same, different), and target format (arrows, words). The target format factor was not of primary interest and was only included to account for variance produced by this factor. We therefore do not report findings related to target format. We note, however, that this factor did not interact with any of the critical findings we report below (i.e., it had no impact on the CSEs we observed).

2.2. Results

2.2.1. Mean RT

The mean RT data are presented in Fig. 1. There were two significant main effects. First, there was a main effect of distracter-target similarity, $F(1,22) = 40.870$, $MSE = 11619$, $p < .001$, $\eta_p^2 = .650$, indicating slower performance when the distracter and target appeared in the same (599 ms) as compared to different (527 ms) perceptual formats. Second, there was a main effect of current congruency, $F(1,22) = 101.902$, $MSE = 3316$, $p < .001$, $\eta_p^2 = .822$, indicating slower performance in incongruent (593 ms) relative to congruent (533 ms) trials. There was no main effect of previous congruency, $F(1,22) = 2.514$, $MSE = 685$, $p = .127$, $\eta_p^2 = .103$.

We also observed three two-way interactions. First, distracter-target similarity interacted with previous congruency, $F(1,22) = 5.651$, $MSE = 965$, $p = .027$, $\eta_p^2 = .204$. More specifically, participants responded more slowly when the previous trial was incongruent relative to congruent, but this effect was greater when the distracter and the target appeared in the same (12 ms) relative to different (−3 ms) perceptual formats. Second, consistent with prior findings indicating that attentional capture increases the congruency effect (Buetti, Lleras, & Moore, 2014; Moore & Weissman, 2010), distracter-target similarity interacted with current congruency, $F(1,22) = 32.525$, $MSE = 2307$, $p < .001$, $\eta_p^2 = .597$: the congruency effect was larger when the distracter and target appeared in the same (89 ms) as compared to different (32 ms) perceptual formats. Both of these congruency effects were significant ($Fs > 50$, $ps < .001$). Third, and also as expected, there was an interaction between previous congruency and current congruency, $F(1,22) = 18.694$, $MSE = 1142$, $p < .001$, $\eta_p^2 = .459$, because the congruency effect was smaller after incongruent (45 ms) as compared to congruent (76 ms) trials.

Finally, we observed a three-way interaction among distracter-target similarity, previous congruency, and current congruency, $F(1,22) = 5.553$, $MSE = 1382$, $p = .028$, $\eta_p^2 = .202$. As hypothesized, the CSE was larger when the distracter and target appeared in the same perceptual format (49 ms; $F(1,22) = 15.618$, $MSE = 1749$, $p < .001$, $\eta_p^2 = .415$) than when they appeared in different perceptual formats (12 ms; $F(1,22) = 2.208$, $MSE = 775$, $p = .151$, $\eta_p^2 = .091$).

2.2.2. Mean percentage error rate

The mean percentage error rate data are presented in Fig. 2. We observed only a single main effect. In particular, there was a main effect of current congruency, $F(1,22) = 16.218$, $MSE = 74$, $p < .001$, $\eta_p^2 = .424$, indicating higher error rates in incongruent (8.8%) than in congruent (5.2%) trials. As in the mean RT data, there was no main effect of previous congruency, $F(1,22) = 2.153$, $MSE = 36$, $p = .156$, $\eta_p^2 = .089$. Unlike in the mean RT data, however, the main effect of distracter-target similarity was also not significant, $F(1,22) = .016$, $MSE = 39$, $p = .902$, $\eta_p^2 < .001$. Further, previous congruency and current congruency did not interact, $F(1,22) = 1.344$, $MSE = 39$, $p = .259$, $\eta_p^2 = .058$. Thus, no CSE was observed in the percentage error rate data. No other effects were significant ($Fs \leq .134$, $ps \geq .718$).

2.3. Discussion

Consistent with our expectations, both the congruency effect and the CSE in mean RT were greater when the target and distracter appeared in the same perceptual format (i.e., word–word and arrow–arrow) as compared to different perceptual formats (i.e., arrow–word and word–arrow). Thus, perceptual similarity between targets and distracters is important for producing a CSE. As we noted earlier, this finding is consistent with both the perceptual conflict and attentional capture accounts. To distinguish between these two accounts, we conducted Experiment 2.

3. Experiment 2

In Experiment 2, we investigated whether our findings in Experiment 1 indexed an influence of attentional capture on the CSE or, alternatively, an influence of perceptual conflict on the CSE. To do so, we randomly varied the perceptual format (word, arrow) of both the distracter and the target on a trial-by-trial basis. Since the target in each trial could be either an arrow or a word, participants had to adopt an attentional set for both perceptual formats. According to the attentional capture account, distracters in both perceptual formats should capture attention, because both formats are goal-relevant. This

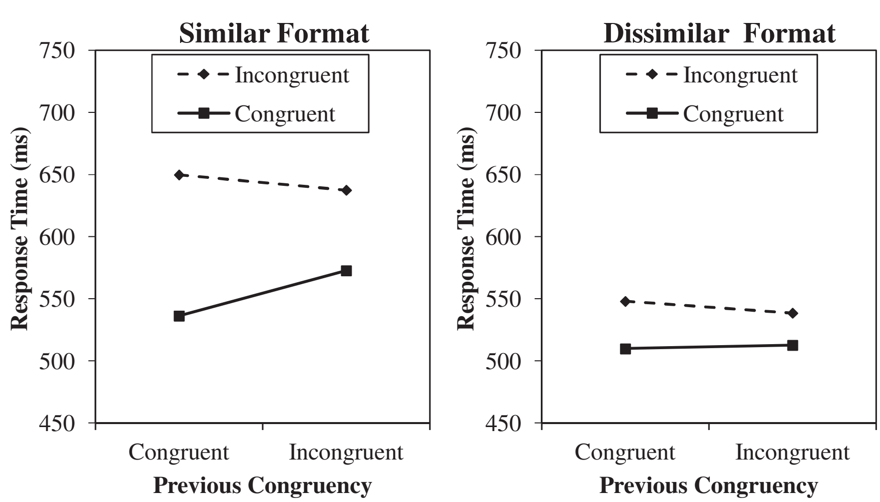

Fig. 1. Mean RT in each of the main conditions of Experiment 1.

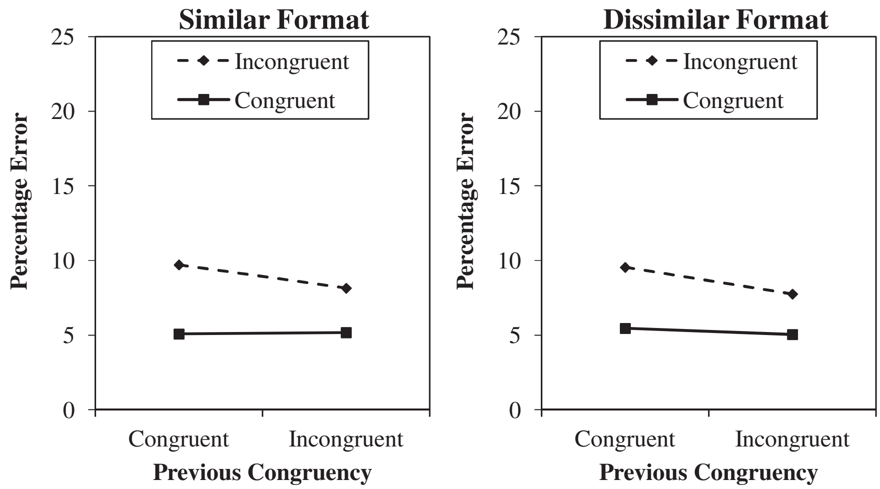

Fig. 2. Mean error rate in each of the main conditions of Experiment 1.

account therefore predicts equivalent CSEs in the same and different perceptual format conditions. According to the perceptual conflict account, the degree to which incongruent stimuli engender greater perceptual conflict than congruent stimuli should always be greater when those stimuli are presented in the same as compared to different perceptual formats. This account therefore predicts a larger congruency effect in the same perceptual format condition than in the different perceptual format condition. It therefore also predicts larger CSEs following trials in which the distracter and target appear in the same as compared to different perceptual formats.

3.1. Method

3.1.1. Participants

Thirty-six Ghent University undergraduates participated in Experiment 2 in exchange for €5. None had participated in Experiment 1.

3.1.2. Apparatus

The apparatus was identical to that in Experiment 1.

3.1.3. Materials and design

The materials and design were identical to those in Experiment 1.

3.1.4. Procedure

The procedure was identical to that in Experiment 1 with one exception. Rather than four separate blocks, there was one large block containing all four versions of the task (i.e., arrow–arrow, word–arrow, word–word, arrow–word), and these conditions were randomly intermixed. There were again a total of 480 trials.

3.1.5. Data analysis

The data analysis was identical to that in Experiment 1. Four participants were excluded for performing with less than 70% accuracy. Unlike the excluded participant in Experiment 1, these four participants did not appear to be responding to the distracter. Instead, they exhibited low accuracy rates for both congruent and incongruent trials, suggesting poor focus on the task. Excluding these participants from the analysis did not modify the critical results reported below in any qualitative way (i.e., the same key findings remained significant). Finally, as in Experiment 1, we included the target format factor in the ANOVA to account for variance stemming from the different target format conditions, but did not report findings related to this factor because it was not of primary interest. As in Experiment 1, this factor did not interact with any of the critical findings (i.e., it had no impact on the CSEs we observed).

3.2. Results

3.2.1. Mean RT

The mean RT data are presented in Fig. 3. There were two main effects. First, there was a main effect of distracter-target similarity, $F(1,31) = 9.914$, $MSE = 1561$, $p = .004$, $\eta_p^2 = .242$, because participants responded more slowly when the distracter and target appeared in the same (611 ms) as compared to different (600 ms) perceptual formats. Second, there was a main effect of current congruency, $F(1,31) = 204.825$, $MSE = 3556$, $p < .001$, $\eta_p^2 = .869$, indicating slower performance in incongruent (643 ms) relative to congruent (567 ms) trials. As in Experiment 1, the main effect of previous congruency was not significant, $F(1,31) = 1.250$, $MSE = 1071$, $p = .272$, $\eta_p^2 = .039$.

We also observed two significant interactions. First, distracter-target similarity interacted with current congruency, $F(1,31) = 8.605$, $MSE = 2170$, $p = .006$, $\eta_p^2 = .217$: unlike in Experiment 1, and inconsistent with the perceptual conflict account, the congruency effect was larger when the distracter and target appeared in different perceptual formats (88 ms) relative to the same perceptual format (63 ms). Second, as expected, there was an interaction between previous congruency and current congruency, $F(1,31) = 17.848$, $MSE = 2030$, $p < .001$, $\eta_p^2 = .365$, indicating a smaller congruency effect following incongruent (62 ms) relative to congruent (89 ms) trials. Critically, consistent with the attentional capture hypothesis, distracter-target similarity did *not* qualify this interaction, $F(1,31) = .057$, $MSE = 1466$, $p = .812$, $\eta_p^2 = .002$. No other effects were significant (Fs ≤ 1.121, ps ≥ .280).

3.2.2. Experiment comparison

Given that we observed a different pattern of results in Experiments 1 and 2, we conducted an across-experiment comparison to investigate whether distracter-target similarity modulated the CSE differentially in the two experiments. Consistent with this view, we observed a marginally-significant four-way interaction among experiment (Experiment 1 vs. Experiment 2), distracter-target similarity (similar vs. dissimilar), previous congruency (congruent, incongruent), and current congruency (congruent, incongruent), $F(1,53) = 3.699$, $MSE = 1431$, $p = .060$, $\eta_p^2 = .065$. That is, the difference in CSE magnitude between the similar and dissimilar perceptual format conditions was larger in Experiment 1 than in Experiment 2, consistent with the attentional capture account.

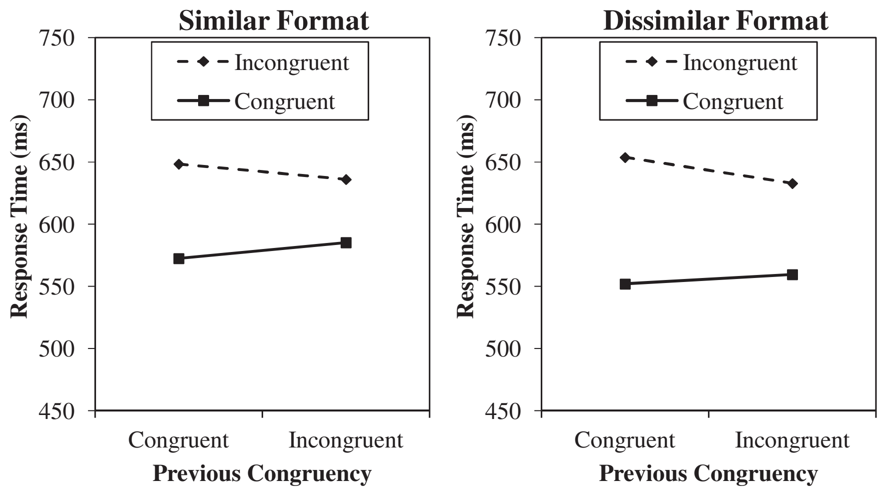

Fig. 3. Mean RT in each of the main conditions of Experiment 2.

3.2.3. Mean percentage error rate

The mean percentage error rate data are presented in Fig. 4. We observed three significant main effects. First, there was a main effect of current congruency, $F(1,31) = 77.507$, $MSE = 87$, $p < .001$, $\eta_p^2 = .714$, because error rates were higher in incongruent (12.8%) relative to congruent (5.5%) trials. Second, there was a main effect of previous congruency, $F(1,31) = 17.328$, $MSE = 47$, $p < .001$, $\eta_p^2 = .359$, indicating higher error rates after congruent (9.1%) relative to incongruent (5.5%) trials. Third, there was a main effect of distracter-target similarity, $F(1,31) = 4.422$, $MSE = 33$, $p = .044$, $\eta_p^2 = .125$, indicating higher error rates in the different perceptual format condition (9.7%) relative to the same perceptual format condition (8.6%).

We also observed two interactions. First, there was an interaction between distracter-target similarity and current congruency, $F(1,31) = 7.555$, $MSE = 57$, $p = .010$, $\eta_p^2 = .196$, indicating a larger congruency effect in the different perceptual format condition (9.1%) relative to the same perceptual format condition (5.4%). Second, as expected, there was an interaction between previous congruency and current congruency, $F(1,31) = 9.558$, $MSE = 44$, $p = .004$, $\eta_p^2 = .236$, because the congruency effect was smaller after incongruent (5.5%) as compared to congruent (9.1%) trials. No other effects were significant (Fs ≤ .746, ps ≥ .395).

3.2.4. Perceptual conflict analysis

There were an insufficient number of trials in the overall analysis to test for an influence of previous-trial perceptual conflict on the CSE. We therefore investigated the perceptual conflict hypothesis in a follow-up analysis. Specifically, we conducted separate repeated-measures of ANOVAs for mean RT and mean error rate with three factors: previous-trial distracter-target similarity (match, mismatch), previous congruency (congruent, incongruent), and current congruency (congruent, incongruent). The RT data are presented in Fig. 5 and the error data are presented in Fig. 6. To avoid redundancy with the main results reported earlier, we report only the two critical comparisons that are relevant for testing the perceptual conflict hypothesis.

Contrary to the perceptual conflict hypothesis, we observed no influence of previous-trial distracter-target similarity on the congruency effect or on the CSE. First, the two-way interaction between previous-trial distracter-target similarity and current congruency was not significant (mean RT: $F(1,31) = .423$, $MSE = 790$, $p = .520$, $\eta_p^2 = .013$; mean error rate: $F(1,31) = 1.709$, $MSE = 17$, $p = .201$, $\eta_p^2 = .052$). Second, the three-way interaction between previous-trial distracter-target similarity, previous congruency, and current congruency was not significant (mean RT: $F(1,31) = .284$, $MSE = 338$, $p = .598$, $\eta_p^2 = .009$; mean error rate: $F(1,31) = .098$, $MSE = 18$, $p = .756$, $\eta_p^2 = .003$).

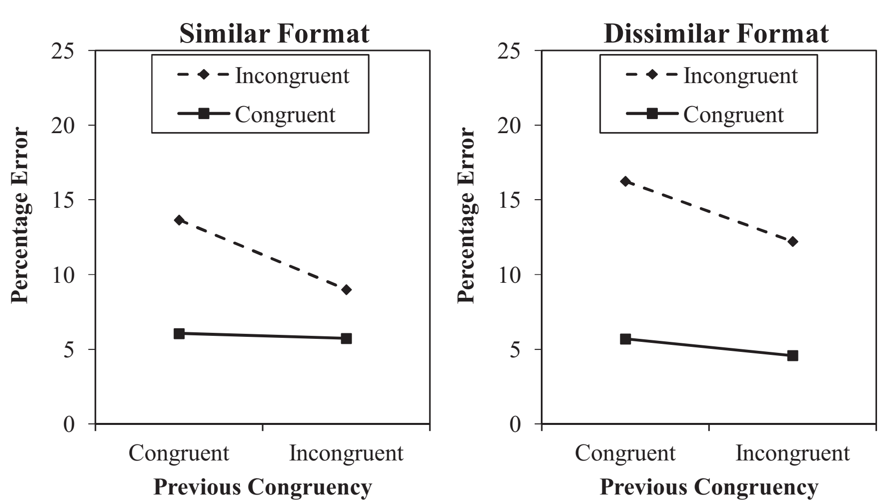

Fig. 4. Mean error rate in each of the main conditions of Experiment 2.

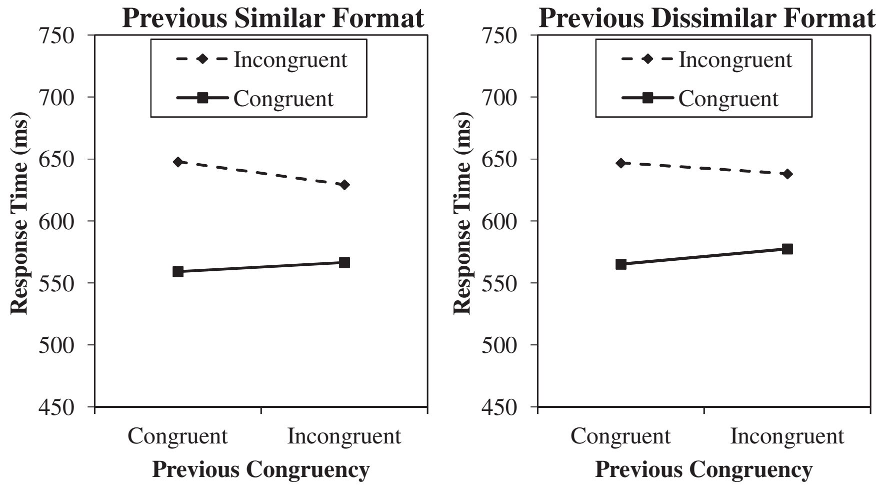

Fig. 5. Mean RT in each of the main conditions of Experiment 2 as a function of previous trial target-distracter similarity.

3.3. Discussion

In Experiment 2, we randomly presented the target in a prime-probe task in either of two possible perceptual formats (i.e., word or arrow), such that participants had to adopt an attentional set for targets that specified the perceptual characteristics of distracters appearing in either format. Consistent with the attentional capture hypothesis, and unlike in Experiment 1, we observed equivalent CSEs in the same and different perceptual format conditions. In addition, whether or not distracters and targets were perceptually similar in the previous trial did not influence the CSE. These findings are more consistent with the attentional capture hypothesis than with the perceptual conflict hypothesis.

4. General discussion

The present findings reveal an important new determinant of whether a CSE can be observed independent of feature integration and contingency learning confounds. Specifically, they reveal that the “confound-minimized” CSE emerges mainly when a distracter possesses a target-defining perceptual feature. More specifically, the CSE is larger when the attentional set participants employ to identify targets specifies the perceptual characteristics of distracters than when it does not. To our knowledge, this is the first demonstration that contingent attentional capture influences the CSE. We discuss the implications of our findings below.

4.1. Relationships between contingent attentional capture, perceptual conflict, and the CSE

Our findings fit with a growing body of work indicating that contingent attentional capture can trigger top-down control. For example, target colors that signal that a response should be inhibited also engender response inhibition when they appear on distracters (Anderson & Folk, 2012). Such findings fit with the view that stimuli possessing target-defining perceptual features enter a limited-capacity focus of attention from which they can update the current attentional set (e.g., for color in Moore & Weissman, 2010). We speculate that distracters possessing a target-defining perceptual feature in the prime-probe task update an attentional set for trial congruency (i.e., congruent or incongruent), resulting in a CSE.

The present findings further suggest that perceptual conflict does not engender a CSE. As we explained earlier, the degree to which incongruent stimuli engender greater perceptual conflict than congruent stimuli is always greater in the same as compared to the different perceptual format condition. Thus, if perceptual conflict triggers the CSE, the CSE should always be larger when the distracter and target in the previous trial appeared in the same as compared to different perceptual

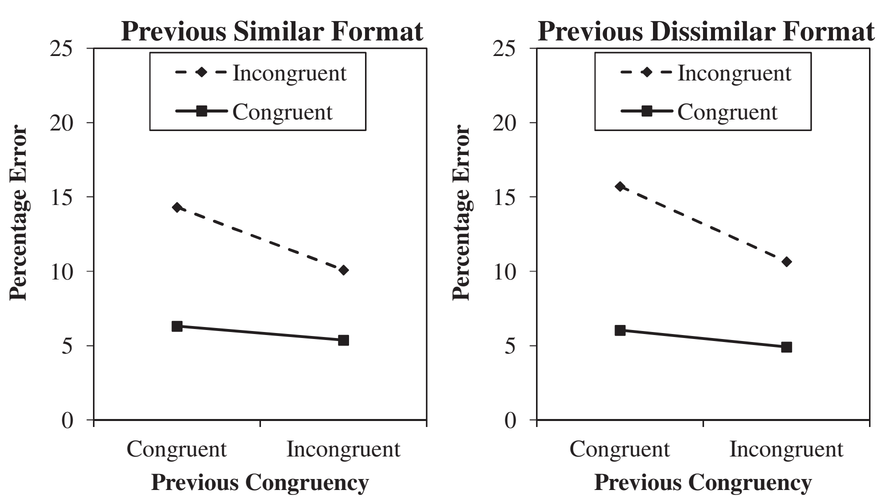

Fig. 6. Mean error rate in each of the main conditions of Experiment 2 as a function of previous trial target-distracter similarity.

formats. Contrary to this prediction, the CSE in Experiment 2 did not vary with previous-trial distracter-target similarity. Thus, our findings are more consistent with the attentional capture hypothesis than with the perceptual conflict hypothesis.

Our finding that perceptual conflict does not engender a CSE may appear at odds with prior work indicating that "stimulus" conflict engenders a CSE. For example, some researchers have reported that a CSE can be engendered by a distracter whose color differs from that of a target, even when the two colors are mapped to the same response (Verbruggen, Notebaert, Liefooghe, & Vandierendonck, 2006; see also, Notebaert & Verguts, 2006). However, distinct colors differ not only at perceptual levels but also at semantic levels, because they are associated with different semantic representations (e.g., see De Houwer, 2003; Schmidt & Cheesman, 2005). Thus, an influence of stimulus conflict on the CSE may index an influence of semantic conflict rather than an influence of perceptual conflict. The present findings are consistent with this view, because they show that perceptual conflict does not influence CSE magnitude.

4.2. The present findings and current accounts of the CSE

To our knowledge, no current account of the CSE formally predicts that contingent attentional capture is necessary to trigger the CSE. This includes accounts in which the CSE indexes a shift of attention toward the target (Botvinick et al., 2001; Dreisbach & Fischer, 2012; Gratton et al., 1992; Hazeltine, Akçay, & Mordkoff, 2011), a modulation of response processing related to the distracter (Logan & Zbrodoff, 1979; Ridderinkhof, 2002), and temporal learning (Schmidt, 2013a). It is therefore useful to consider whether and how various accounts of the CSE might or might not be able to explain the present findings.

We begin with one of the most influential accounts of the CSE – the conflict monitoring account. In this account, the CSE indexes a control process that is triggered by response conflict regardless of its source (Botvinick et al., 2001; Yeung, Cohen, & Botvinick, 2011). Thus, the larger CSE in the same (versus different) perceptual format condition of Experiment 1 could have been driven by the larger congruency effect – a robust measure of response conflict – in that condition, which resulted from the distracter capturing attention to a greater degree.

While we cannot rule out this possibility with the present data, we can say with confidence that "confound-minimized" CSEs in the prime-probe task are not generally driven by the size of the congruency effect (Weissman et al., 2014, 2015). As a rather extreme example, CSE magnitude in the prime-probe task does not vary with whether a congruency effect is present or absent (Weissman et al., 2015, Experiment 3). Nonetheless, even if the conflict monitoring account was employed to explain why the CSE was greater in the same (versus different) perceptual format condition of Experiment 1 (e.g., because the congruency effect was larger in this condition), it would have difficulty explaining the complete absence of a CSE in the different perceptual format condition. Indeed, the highly significant 32 ms congruency effect in that condition should still have engendered a CSE, albeit a smaller one than in the same perceptual format condition. The conflict monitoring account would also have difficulty explaining why the CSE in Experiment 2 did not vary with whether the distracter and target appeared in the same as compared to different perceptual formats, because the congruency effect was larger in the latter case than in the former one. Thus, in its current form, the influential conflict monitoring account has difficulty explaining the pattern of CSEs that we observed.

We next consider the activation-suppression account of the CSE (Ridderinkhof, 2002). In this account, early response activation engendered by the distracter is gradually suppressed to avoid conflict with the correct response. Evidence for suppression is particularly apparent in the prime-probe and Simon tasks (Burle, van den Wildenberg, & Ridderinkhof, 2005). For these tasks, the activation-suppression account assumes that both the response associated with the distracter and, in fact, the entire distracter processing pathway are suppressed to a greater degree following incongruent as compared to congruent trials, resulting in a CSE (Wylie, Ridderinkhof, Bashore, & van den Wildenberg, 2010). This account may explain the present findings by assuming that control processes underlying response suppression are triggered most effectively by distracters possessing target-defining perceptual features. Notably, this possibility is consistent with prior work indicating the importance of attentional set for triggering response suppression (Anderson & Folk, 2012; Chiu & Aron, 2014).

Finally, we consider the temporal learning account of the CSE (Schmidt, 2013a; Schmidt & Weissman, submitted for publication). In this account, participants generate expectancies about when to respond based on previous response times (Schmidt, 2013b, 2014; Schmidt, Lemercier, & De Houwer, 2014). This rhythmic bias produces a shortcutting of responses on congruent following congruent trials and incongruent following incongruent trials, resulting in a CSE.

The temporal learning account might be adapted to explain the present findings by assuming that distracters provide stronger cues for timing when they possess target-defining perceptual features than when they do not. For instance, a distracter that captures attention might produce a stronger "onset marker" and/or "offset marker" in memory, which allows the participant to better anticipate when the target will appear and when a response should be executed (e.g., French, Addyman, Mareschal, & Thomas, 2014). Consistent with this possibility, "confound-minimized" CSEs are most apparent in paradigms that present attention-grabbing cues just before targets, such as distracters in a prime-probe task and rapidly-processed spatial information in the Simon task (Weissman et al., 2014).

Whatever account ultimately explains the present findings, the "confound-minimized" CSE appears to index a control (or learning) process whose involvement in regulating distraction is maximal when distracters capture attention. While this characteristic may not have been previously considered in extant accounts of the CSE (e.g., Botvinick et al., 2001), it could have tremendous value for organisms like humans that create attentional sets to guide goal-directed behavior. As an everyday example, many drivers feel an urge to accelerate through a red light when perceiving the "left turn only lane" traffic light turn green, because the color green is behaviorally-relevant and therefore captures attention. A process that is maximally recruited when an organism needs to regulate distraction from stimuli possessing target-defining perceptual features could therefore be quite valuable in everyday life.

4.3. Limitation

Although we have interpreted the influence of distracter-target similarity on the CSE as indexing an influence of contingent attentional capture, one might wonder whether it instead indexes an influence of repetition blindness. Specifically, one might wonder whether, in the similar perceptual format condition, target processing in congruent trials is impaired by the pre-presentation of a perceptually-similar distracter (Wühr & Müsseler, 2005) and whether previous-trial congruency modulates this impairment to engender a larger CSE in the similar as compared to the dissimilar format condition (as we observed in Experiment 1). As we discuss next, our findings generally do not support this possibility.

In our view, a repetition blindness account cannot explain the present findings for two reasons. First, repetition blindness for the target in congruent trials of the similar format condition should engender increased response times, thereby reducing the size of the congruency effect in the similar as compared to the dissimilar format condition. In Experiment 1, however, we observed a larger congruency effect in the similar as compared to the dissimilar format condition. Thus, the data from Experiment 1 do not appear compatible with a repetition blindness account. Second, although a repetition blindness account can explain the reduced congruency effect that we observed in the similar (versus dissimilar) format condition of Experiment 2, such an account has difficulty explaining why the CSE in this experiment did not differ between the similar and dissimilar format conditions. To do so, it would need to predict that previous-trial congruency does not influence the CSE by modulating repetition blindness in current congruent trials. However, this prediction directly contradicts the repetition blindness account's explanation of the larger CSE in the similar (versus) dissimilar format condition of Experiment 1. Thus, unlike the attentional capture account, the repetition blindness account does not appear to provide an internally consistent explanation of the pattern of CSEs we have observed.

4.4. Conclusion

The present findings show for the first time that contingent attentional capture plays a moderating role in triggering the CSE. This result provides a novel link between the CSE and attentional capture literatures, which have proceeded largely independently of one another. It also indicates that at least some accounts of the CSE may need to be revised. Future studies investigating the role that attentional capture plays in triggering the CSE may therefore continue to yield important information about how control (or learning) processes regulate distraction from irrelevant stimuli.

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