Contextual Influences on the Sequential Congruency Effect

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Abstract

The Sequential Congruency Effect (SCE) refers to the reduction in the size of the congruency effect following incongruent relative to congruent trials. Prior evidence indicates that the SCE does not generalize across tasks or different conflict producing feature dimensions. We present results from a Stroop task showing that when the local list context is such that all colors and words appear in the same proportion of congruent trials, the SCE is present, but when those same items vary in the proportion congruent, the SCE is absent. We suggest if there is sufficient consistency across stimuli in the informativeness of stimulus dimensions for responses, then individuals will attempt to track such information and weight the dimensions accordingly. In this way, the SCE reflects sequential adjustments to the weights given to individual stimulus dimensions in an attempt to track this information.

Contextual Influences on the Sequential Congruency Effect

Studies of cognitive control focus on how particular cognitive processes are engaged and inhibited in the service of goal directed behavior. To address this in the laboratory, individuals are presented with stimuli consisting of two dimensions and asked to report the value of a single relevant dimension. Typically, response time (RT) is slower when the stimulus dimensions are incongruent than when congruent, suggesting difficulty in inhibiting processing of the irrelevant dimension. This difference in RT is referred to as the *congruency effect* and large congruency effects are commonly associated with lower levels of control and small congruency effects with greater levels of control (Botvinick, Braver, Barch, Carter, & Cohen, 2001; Verguts & Notebaert, 2008).

Conflict monitoring (Botvinick et al., 2001) refers to a feedback mechanism that detects conflict, defined as the activation of multiple responses, and signals the need for increased selectivity. This increased selectivity is observed as the decrease in the congruency effect following trials producing conflict (typically incongruent trials) compared to trials generally absent conflict (typically congruent trials) (Gratton, Coles, & Donchin, 1992). This sequential modulation of the congruency effect is generally referred to as conflict adaptation. Here, we use the more theoretically neutral *sequential congruency effect* (SCE) to separate the effect from the theoretical interpretation.

The way in which this signal is thought to increase selectivity has evolved considerably since originally proposed. At present, at least three general statements about the SCE are well (if not unanimously) supported by the available evidence. First, the SCE occurs in the absence of overlap between trial N and N+1 stimulus features

(Kerns et al., 2004; Notebaert, Gevers, Verbruggen, & Liefooghe, 2006). This suggests a change in selectivity not driven by simple feature repetition. Second, the SCE occurs within rather than across tasks. Thus, if trial N and trial N + 1 involve different tasks, no SCE is observed (Fernandez-Duque & Knight, 2008; Funes, Lupiáñez, & Humphreys, 2010). However, one can observe a SCE between trials N and N+2 if trial N + 1 is drawn from another task (Funes et al, 2010). Third, within a task, the SCE is specific to the dimension producing conflict. For example, a task that combines Simon and Flanker stimuli shows modulation of the Simon effect on trial N + 1 in response to Simon conflict on trial N, and the modulation of the Flanker effect on trial N+1 in response to Flanker conflict on trial N. However, Simon conflict does not modulate the Flanker effect and vice versa (Akçay & Hazeltine, 2011). Combined, these appear consistent with adjustments that are separable from specific stimulus features, but that modulate processing for specific stimulus dimensions.

Because conflict occurs when a stimulus dimension incorrectly predicts a response, conflict monitoring is a mechanism that would allow the system to weight stimulus dimensions by how accurately each dimension predicts the correct response (cf. Melara & Algom, 2003).

Item Specific Proportion Congruence

Complicating the preceding picture are item level manipulations (see: Bugg & Crump, 2012 for a review). In the Stroop task, one can construct stimulus lists such that particular words are more likely to occur in an incongruent condition while other words are more likely to occur in a congruent condition, while maintaining an equal proportion of incongruent and congruent trials. This ensures an equal probability that prior trials are congruent or incongruent. The item specific proportion congruence (ISPC) effect (Jacoby, Lindsay, & Hessels, 2003) refers to the finding that words with a high proportion of incongruent occurrences are associated with smaller congruency effects compared to those with a high proportion of congruent occurrences.

There have been two accounts advanced to explain the ISPC effect. One extends the conflict monitoring mechanism, suggesting a form of *item level control* whereby individual words and colors become associated with unique control settings based on the probability of conflict (Blais, Robidoux, Risko, & Besner, 2007; Bugg, Jacoby, & Toth, 2008). In contrast, a contingency account suggests that individuals learn to use word information to predict the response (Schmidt, 2013; Schmidt & Besner, 2008). As described, item level control modulates the influence of word information based on the specific word's prior informativeness about a congruent response (Blais et al., 2007). Because this adjustment is based on the contingent relationship between the word, color and the response, item level control will have the effect of encoding individual word-response contingencies.

Here, we do not try to distinguish between item level control and the contingency accounts. Instead, our question is how the variation in the informativeness of the word dimension might relate to the more general SCE. Note that in item level manipulations, the variability in congruency of individual words means that a dimension level weighting of word information is less accurate than for lists with words containing equal proportions of congruent trials. If the SCE functions as a mechanism that helps to set the appropriate weighting of stimulus dimensions during processing, then the presence of item level variability may discourage such sequential adjustments and hence reduce or eliminate the SCE.

Experiments 1A and 1B

In Experiments 1A and 1B, we simply asked whether the SCE can be observed in the context of an item level manipulation. We report results from two different experiments that were conducted at different times with different participants and implement slightly different list structures. Because one possible outcome is the lack of an SCE, the ability to replicate such a finding is important.

Experiment 1

Method

Participants

Participants were recruited from the Georgia Institute of Technology undergraduate population and received course credit. Ages ranged from 18 to 23. Experiment 1A consisted of 24 participants (M Age = 20.1) and Experiment 1B consisted of 24 participants (M Age = 19.8). One participant in Experiment 1A was removed due to an error rate above 40%.

Materials and Stimuli

All experiments used Eprime 2.0 software (Psychology Software Tools, Pittsburgh, PA) to control the display of stimuli and record RTs. Stimuli were displayed on a 14-in color (VGA) monitor. A microphone connected to a Psychology Software Tools Serial Response Box™ measured voice onset time. Words were presented against a gray background with each letter subtending 0.17 degree of visual angle.

Experiment 1A

Six color words (“black”, “blue”, “green”, “red”, “white”, and “yellow”) were displayed in one of the six corresponding colors. Stimulus lists were constructed by creating two color/word sets. For a given participant three of the six colors/words were presented in the mostly congruent condition and the remaining three colors/words were presented in the mostly incongruent condition. Within the mostly congruent condition, a given word appeared as congruent on 60 trials and as incongruent on 20 trials. Within those 20 incongruent trials, each word was paired on 10 trials with each of the remaining members of the set. The same distribution was used for all members of the set. In the mostly incongruent condition, each word appeared as a congruent trial 20 times and as an incongruent trial 60 times. Within those 60 incongruent trials, each word was consistently paired with one member from the set. The same distribution was used for each member of the set. Participants performed 5 blocks of 96 trials for a total of 480 trials. Stimulus lists were counterbalanced across participants such that each color/word appeared an equal number of times as a mostly congruent and mostly incongruent item.

Experiment 1B

Four color words (“blue”, “green”, “red”, and “yellow”) were displayed in one of the four corresponding colors. Stimulus lists were constructed using color/word pairs. This meant that a given word would appear in its matching color and in only one nonmatching color. For a given participant one of the color/word pairs was presented in the mostly congruent condition and the remaining pair was presented in the mostly incongruent condition. Within the mostly congruent condition, a given word appeared as congruent on 30 trials and as incongruent on 10 trials. In the mostly incongruent condition, each word appeared as a congruent on 10 trials and as incongruent on 30 trials.

This resulted in a total of 160 trials[1]. Stimulus lists were counterbalanced as in Experiment 1A.

Procedure

All participants were instructed to ignore the word and name the color in which the word was displayed as quickly as possible while maintaining a high degree of accuracy. The following sequence of events occurred on each trial: a) three fixation crosses ("+ + +") were presented in the center of the screen for 500 ms, b) there was a blank screen for 200 ms, c) the stimulus was presented and remained on the screen until a vocal response was detected, d) the screen cleared for the 500 ms intertrial interval. Participants performed 20 practice trials consisting of an equal number of congruent and incongruent trials. Participants were tested individually while seated next to an experimenter who coded incorrect responses and voice key errors. The entire experimental session lasted 1 hour.

Results

An alpha level of .05 was used for all reported results. Prior to all analyses, incorrect responses, voice key errors, RTs greater than 2500 ms and RTs less than 200 ms were excluded. The trimming procedure resulted in a removal of 4.7% (1A) and 4.1% (1B) of all trials. The range in accuracy for the cells in the analyses reported below was between 94.5% and 99% across the two datasets. We do not report statistical analyses of error rates both because the rates are low and because it is difficult to detect error responses in the congruent condition.

ISPC Analysis

To demonstrate the typical ISPC effect, the data were analyzed in separate 2 Item Type (Mostly Congruent, Mostly Incongruent) X 2 Current Trial Congruency (Congruent, Incongruent) repeated measures analysis of variance (ANOVA). As seen in Table 1, each shows a main effect of Current Trial Congruency 1A: $F(1, 22) = 114.10$, $MSE = 1487$, 1B: $F(1, 23) = 43.12$, $MSE = 3562$ and both datasets show the ISPC effect as reflected in the modulation of Current Trial Congruency by Item Type, 1A: $F(1, 22) = 46.61$, $MSE = 748$ and 1B: $F(1, 23) = 6.12$, $MSE = 1819$.

SCE Analysis

For this analysis, we also excluded trials in which the color dimension or word dimension overlapped on the previous trial, removing all color or word repetitions (Kerns et al., 2004). In addition, for Experiment 1A we excluded trials in which item type repeated. This is functionally equivalent to removing color and word repetitions in Experiment 1B. These criteria resulted in a removal of 40.9% (1A) and 48.9% (1B) of all trials. Across the experiments, each participant contributed a minimum of 18 trials to each cell in the analysis.

Data from each experiment were analyzed in separate 2 Previous Trial Congruency (Congruent, Incongruent) X 2 Current Trial Congruency (Congruent, Incongruent) repeated measures ANOVAs. As seen in Figure 1, each dataset showed a main effect of Current Trial Congruency 1A: $F(1,22) = 67.05$, $MSE = 2413$, 1B: $F(1,23) = 44.73$, $MSE = 2946$. The main effect of Previous Trial Congruency was significant only in 1A: $F(1,22) = 5.19$, $MSE = 932$. Importantly, there was no modulation of Current Trial Congruency by Previous Trial Congruency, $Fs < 1$. Therefore, across two ISPC manipulations, we find no evidence for the SCE[2].

Discussion

The results of Experiment 1 are consistent with the suggestion that when words are differentially informative of a congruent response, the SCE is absent. Note that prior studies have shown the absence of SCE across tasks or stimulus properties. Here, the distinction between words is not based on predefined task sets (Funes et al., 2010) or differences in perceptual or response features (Hazeltine, Lightman, Schwarb, & Schumacher, 2011). Instead, the distinction between words is established within the context of the experiment.

We acknowledge that our conclusions from Experiments 1A and 1B are based on a null finding. Experiment 2 is designed to more directly test whether list context determines the presence of the SCE. Here, participants perform blocks of trials in which words are differentially informative of a congruent response (item blocks) and blocks in which words are equally informative of a congruent response (balanced blocks). We have suggested that the SCE reflects a sequential updating of an estimate of the informativeness of the word dimension. Moreover, consistency encourages individuals to track such informativeness at the level of the word dimension while item variability discourages such attempts to track informativeness at the dimension level. If so, balanced blocks should demonstrate the SCE, while item blocks should not.

Experiment 2

Method

Participants

Forty-eight participants were drawn from the same pool as Experiment 1, and ranged in age from 18 to 22 (M=19.7).

Materials and Stimuli

Four color words ("blue", "black", "green", and "red") were displayed in one of the four corresponding colors. Similar to Experiment 1B, stimulus lists were constructed using color/word pairs. This meant that a given word would appear in its matching color and in only one nonmatching color.

Balanced blocks consisted of each word appearing in its matching color on 10 trials and in a non-matching color on 10 trials. In item blocks, for mostly congruent items, each word appeared in its matching color on 15 trials and in a non-matching color on 5 trials. For mostly incongruent items, each word appeared in its matching color on 5 trials and in a non-matching color on 15 trials. Participants performed four blocks of 80 trials for a total of 320 trials.

Procedure

Half of the participants performed two item blocks followed by two balanced blocks, and half the participants performed two balanced blocks followed by two item blocks. Participants were not informed of any differences between the blocks. Participants performed 16 practice trials consisting of an equal proportion of congruent and incongruent trials. Instructions, timing and response coding was identical to that reported in Experiments 1A and 1B.

Results

An alpha level of .05 was used for all reported results. Data were excluded using the same criteria as Experiment 1. This resulted in a removal of 5.2% of all trials. Accuracy ranged between 93.5% and 99% for all cells reported below. Due to this low error rate, analysis of errors is not reported.

ISPC Analysis

Word-color pairs were consistent through the experiment. Therefore, pairs presented together in Balanced blocks were also presented together in Item blocks. In this analysis, we simply show that performance on these pairs is different as a function of block type. The data were analyzed in a 2 Block Order (Balanced First, Item First) X 2 Block Type (Balanced, Item) X 2 Item Type (Mostly Congruent, Mostly Incongruent) X 2 Current Trial Congruency (Congruent, Incongruent) repeated measures ANOVA with Block Order as a between-subjects factor.

Consistent with Experiment 1, we observe a main effect of Current Trial Congruency $F(1, 46) = 222.99$, $MSE = 4095$ and Current Trial Congruency modulated by Item Type $F(1, 46) = 38.22$, $MSE = 862$. Further, we observe Item Type modulated by Block Type, $F(1,46) =6.89$, $MSE = 646$ suggesting performance on pairs in the Balanced block is different than performance in the Item block. More importantly, we observed the three-way interaction of Block Type X Item Type X Current Trial Congruency, $F(1, 46) = 19.18$, $MSE = 1231$, driven by an ISPC effect in the Item (77 ms) but not Balanced (5 ms) blocks. Finally, we observed a Block Order X Item Type X Current Trial Congruency interaction, $F(1, 46) = 13.69$, $MSE = 852$. This is driven by a larger ISPC effect when Item blocks are presented first (89) than last (48) (see Table 1). Block Order did not interact with any other factors. These data suggest that item effects are dependent upon the local list context, and when that list context changes to an equal proportion of congruent trials for all items, the ISPC effect is eliminated.

SCE Analysis

As in Experiment 1B, we removed trials in which the color dimension or word dimension overlapped on the previous trial. In total, 37.4% of trials were excluded. Shown in Figure 2, regardless of order, Balanced blocks show the SCE while the Item blocks do not. The data were analyzed in a 2 Block Order (Balanced First, Item First) X 2 Block Type (Item, Balanced) X 2 Previous Trial Congruency (Congruent, Incongruent) X 2 Current Trial Congruency (Congruent, Incongruent) repeated measures ANOVA with Block order as a between subjects factor. We observed a main effect of Previous Trial Congruency, $F(1, 46) = 39.77$, $MSE = 992.83$, Current Trial Congruency, $F(1, 46) = 170.36$, $MSE = 5048$ and Block Order, $F(1, 46) = 4.07$. However, Block Order did not interact with any other factor. In addition, the effect of Current Trial Congruency was modulated by Previous Trial Congruency, $F(1, 46) = 13.65$, $MSE = 526$. More importantly, a 3-way Block Type X Previous Trial Congruency X Current Trial Congruency interaction was observed, $F(1, 46) = 7.29$, $MSE = 1114$, consistent with the observation in Figure 2 that the SCE effect is present for Balanced but absent for the Item blocks.

Separate analyses of the Balanced and Item Blocks showed a Previous Trial Congruency X Current Trial Congruency interaction for Balanced, $F(1,47) = 15.59$, $MSE = 981$ but not Item blocks, $F(1, 47) = .024$, $MSE = 632$. This is driven by a SCE (98 ms vs. 64 ms congruency effect for prior congruent and incongruent trials respectively) for balanced blocks that is absent (108 ms vs. 110 ms) for item blocks.

Item Specific Sequential Adjustments

Participants at the beginning of an experiment are generally not informed about the presence of item level manipulations, but Experiment 2 suggests that the ISPC effect can emerge relatively rapidly given the appropriate list context. This suggests individuals continually encode information about how individual words are predictive of a congruent response. When all words are similarly predictive, then the SCE emerges, reflecting a process of tracking the informativeness of stimulus dimensions, while tracking of individual word (and color) relations with responses continues in parallel. In this account, there continues to be item level encoding of information in balanced lists but the design of such lists does not allow one to separately demonstrate such effects (e.g. Blais & Bunge, 2010).

An example of such item sensitivity would be the finding that if a given word (or color) appeared in the incongruent condition, then on the next occurrence of that word (or color), the congruency effect would be reduced compared to when the previous occurrence was congruent. This is essentially the description of the SCE but tied to specific words or colors, and spanning multiple intervening trials. This sequential effect must be present in the Item block for the demonstration of the ISPC effect. We ask if that relation is also present in the Balanced blocks of trials. We examined data from the 24 participants who performed Balanced blocks first. We chose this portion of the data to eliminate the possibility of any residual effect of items previously presented in an item context. Data were analyzed using a 2 Previous Word Congruency (Congruent, Incongruent) X 2 Current Word Congruency (Congruent, Incongruent) repeated measures ANOVA. As seen in Figure 3, in addition to the main effects of Current and Previous Word Congruency, $F(1, 23) = 134.98$, $MSE = 192721$ and $F(1,23) = 8.39$ $MSE = 6935$ respectively, Current Word Congruency was modulated by Previous Word Congruency $F(1, 23) = 7.99$ $MSE = 7337$, mirroring the pattern observed in the conventional SCE.

While space precludes reporting further analyses, a similar item specific sequential adjustment is also present when the analysis is repeated with colors rather than words.

These data suggest that while the SCE is present in Balanced blocks and absent in Item blocks, the tracking of information at the item level may be present regardless of list context.

General Discussion

Across three datasets, the SCE is absent when words are differentially predictive of a congruent response, but present when words are equally predictive of such a response. Experiment 2 clearly indicates that it is the local list context that determines the presence or absence of the SCE. When all words are equally predictive of a congruent response, then the SCE is present, reflecting the sequential updating of weights assigned to the word dimension as a whole. If the local list context manipulates the proportion congruent at the individual word level, then the SCE is absent, reflecting the lack of an appropriate dimension wide weighting of word information.

We argue that the contribution of these results does not depend upon whether the account for the ISPC effect emphasizes an item specific control mechanism (Blais et al., 2007; Bugg & Hutchison, 2012) or the learning of contingencies between individual words and their associated responses (e.g. Schmidt & Besner, 2008). Given that the congruency effect for an individual word or color is influenced by the prior occurrence of that word or color, as we observed above, item properties are continually encoded regardless of the local list context (e.g. Hommel, 2004). On the other hand, if the SCE reflects individuals' attempt to arrive at a more general, dimension level weighting of word and color information, this seems very consistent with a control-like function.

Here, the goal is to modulate the contribution of distinct processing streams, and such a weighting applies across specific values (e.g. words) on a dimension (e.g. Cohen, Dunbar, & McClelland, 1990). Such a dimension level weighting does not require the detailed representation of individual word or color histories, nor does it require the rapid modification of such control settings based on these individual histories.

We interpret the absence of the SCE in item level manipulations as reflecting the treatment of individual items as distinct sources of information. It is only when these individual sources of information are consistent that the SCE is observed. This interpretation represents an important refinement to both the conflict monitoring and contingency accounts.

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Footnotes

[1] Experiment 1B was followed by trials designed to probe aspects of the ISPC effect. From the standpoint of the participants this later manipulation was invisible.

[2] Analyses of an additional dataset using the same stimulus list as 1B but with 16 different participants also failed to show the SCE. These data are not reported because of space limitations.

	Mostly Congruent Items		Mostly Incongruent Items		
	Congruent	Incongruent	Congruent	Incongruent	ISPC Effect
Experiment 1					
A	657 (17)	783 (12)	690 (12)	740 (13)	76
B	608 (16)	710 (23)	624 (22)	682 (15)	44
Experiment 2					
Item First	590 (10)	752 (21)	621 (15)	694 (14)	89
Balanced First	558 (16)	687 (21)	572 (16)	653 (17)	48

Table 1. Mean response times (in milliseconds) and 95% within-subjects confidence intervals (in parentheses) for trial condition as a function of item type across the four item manipulations.

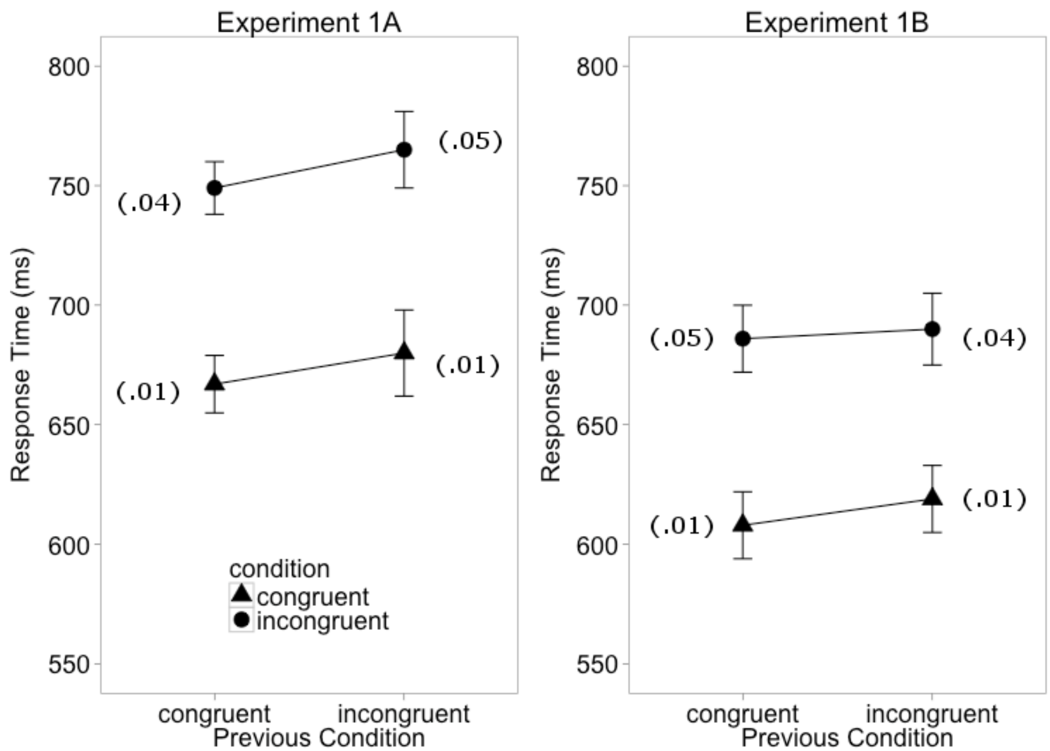

Figure 1. Response Time (RT) as a function of Previous Trial Condition and Current Trial Condition across Experiments 1A and 1B. Error bars represent 95% within-subjects confidence intervals. Error proportions are shown in parentheses next to the corresponding point.

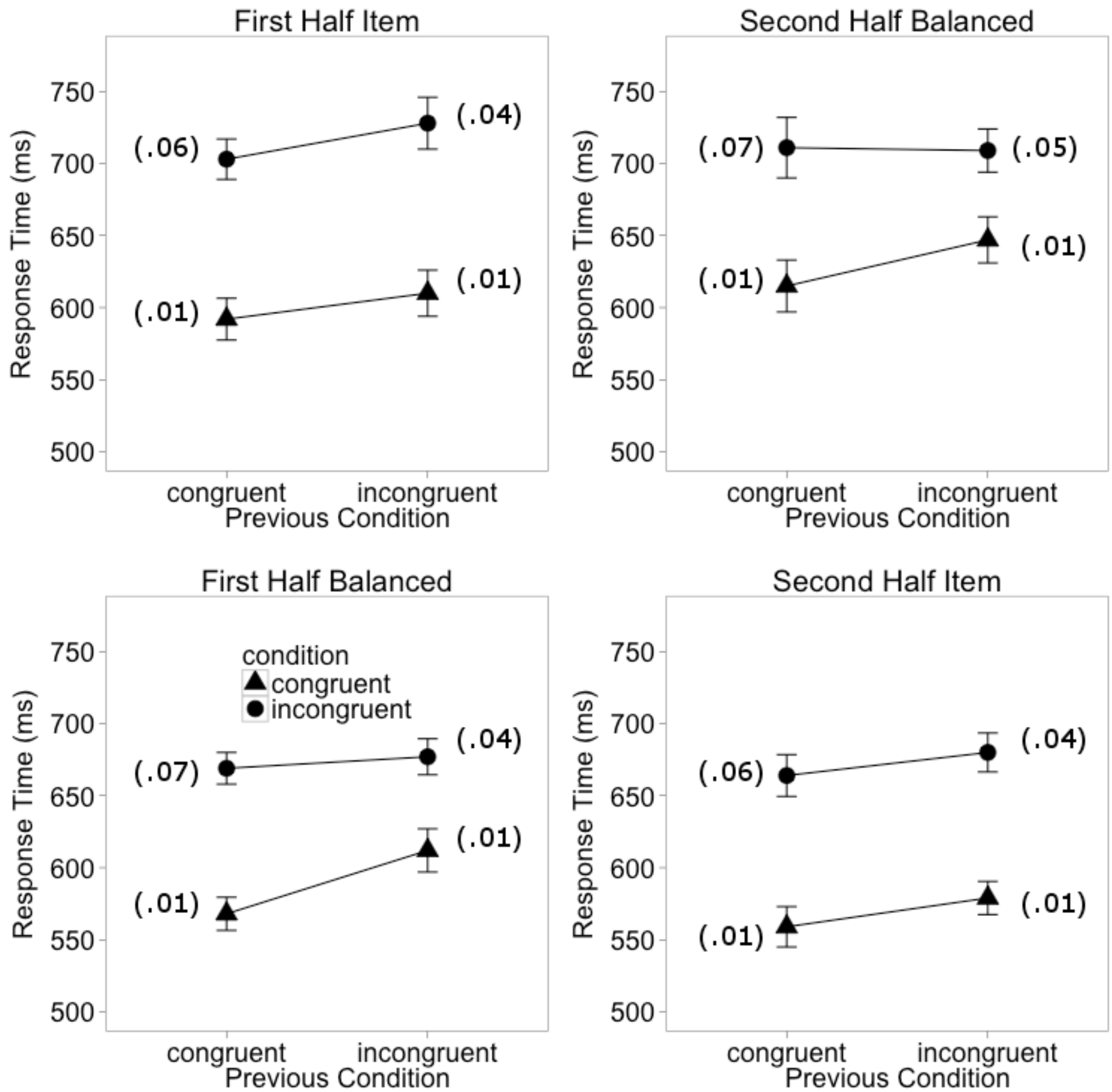

Figure 2. Response Time (RT) as a function of Previous Trial Condition and Current Trial Condition for Experiment 2. Error bars represent 95% within-subjects confidence intervals. Error proportions are shown in parentheses next to the corresponding point.

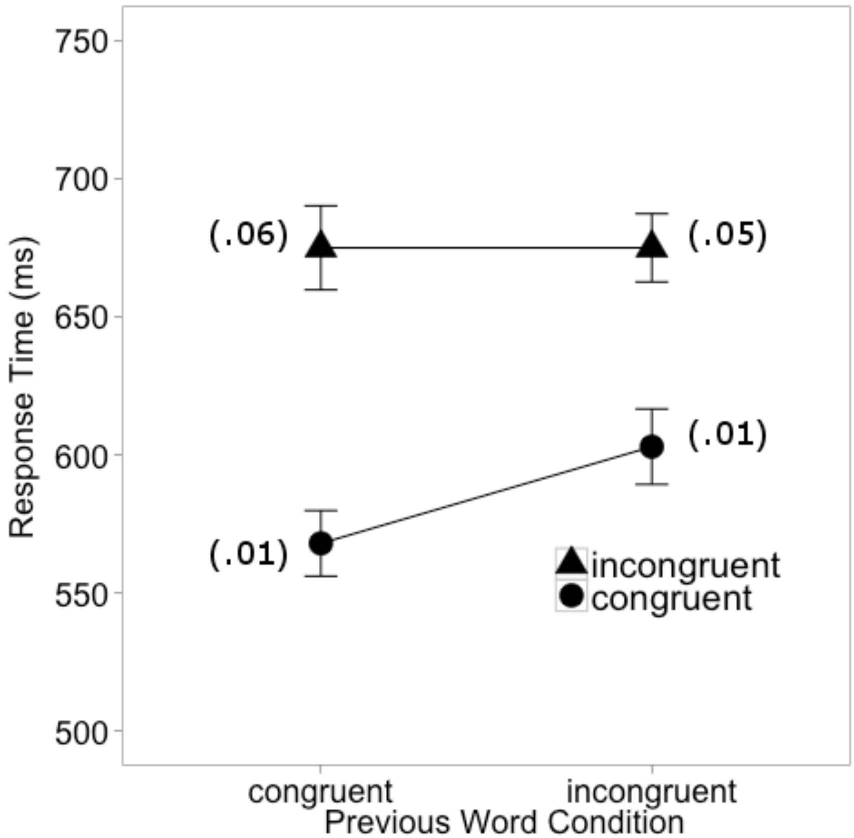

Figure 3. Response Time (RT) as a function of the condition in which the current word previously occurred for participants who performed the balanced blocks first in Experiment 2. Error bars represent 95% within-subjects confidence intervals. Error proportions are shown in parentheses next to the corresponding point.