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# Contingency learning is reduced for high conflict stimuli

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ABSTRACT

Recent theories have proposed that contingency learning occurs independent of control processes. These parallel processing accounts propose that behavioral effects originally thought to be products of control processes are in fact products solely of contingency learning. This view runs contrary to conflict-mediated Hebbian-learning models that posit control and contingency learning are parts of an interactive system. In this study we replicate the contingency learning effect and modify it to further test the veracity of the parallel processing accounts in comparison to conflict-mediated Hebbian-learning models. This is accomplished by manipulating conflict to test for an interaction, or lack thereof, between conflict and contingency learning. The results are consistent with conflict-mediated Hebbian-learning in that the addition of conflict reduces the magnitude of the contingency learning effect.



## 1. Introduction

Stroop (1935) was the first to show that it is difficult to report the ink color of a color word (i.e. identifying the color blue for the word RED written in blue ink). The ubiquitous finding is that incongruent stimuli (i.e. RED written in blue ink; $RED_{BLUE}$) are responded to slower than congruent stimuli (i.e. $RED_{RED}$), the so-called Stroop effect. Current accounts of the Stroop effect suggest that it occurs because the strength of association between the word and its response is stronger than the strength of association between the color and its response (i.e., Cohen, Dunbar, & McClelland, 1990; MacLeod & Dunbar, 1988). More recent additions to this idea stipulate the amount of response conflict (Botvinick, Braver, Barch, Carter, & Cohen, 2001; Botvinick, Cohen, & Carter, 2004) or likelihood of committing an error (Brown & Braver, 2005) cause micro-adjustments in the amount of top-down control on a trial-by-trial basis (see MacDonald, Cohen, Stenger, & Carter, 2000). This conflict-monitoring hypothesis maintains that conflict is detected by the anterior-cingulate cortex (ACC), which functions as a performance monitor, and then recruits executive functions in the dorsolateral prefrontal cortex (DLPFC) in order to mediate the conflict. Behavioral indices such as the sequential-congruency effect (Gratton, Coles, & Donchin, 1992) and error-related slowing (Rabbitt, 1966) are widely thought to reflect the operation of this ACC-DLPFC system.

Although this interpretation is widely accepted, it is not without its critics (e.g., Grinband et al., 2011; Schmidt, 2013). Much of this criticism stems from the philosophical position that cognitive control, the mental processes which help coordinate and adapt behavior to meet situational demands like those found in the Stroop task, must be volitional. For example, Schmidt and de Houwer (2011) showed that low-level stimulus information – feature repetitions and the frequency with which the color and the word dimensions co-occur (i.e., contingency) – can entirely explain the sequential congruency effect under some conditions (but see Blais, Stefanidi, & Brewer, 2014). They therefore argued that the sequential congruency effect can not be a product of cognitive control.

In an attempt to reconcile these ideas, Egner (2014) argues that lower level processes such as feature integration, and higher level processes such as response selection, are components along a continuous hierarchy of cognitive control. More concrete levels include processes involved in associating physical stimulus features with specific motor responses, as well as those involved in specifying how perceptual identification of the stimulus and stimulus-response (S-R) learning occurs. More abstract levels include processes that are relatively generalizable, such as those involved in goal maintenance, performance monitoring, and binding contextual cues to internal processing states or strategies. These concrete and abstract features are encoded and bound together into a dynamic event file in memory (Hommel, 1998). The occurrence of any one of these features triggers the retrieval of this event file, reducing the reliance on the slower more effortful top-down processes (see also Logan, 1988). This framework offers an appealing resolution to the fact that sequential congruency effects (Gratton et al., 1992) can arise from both lower-level S-R learning (Mayr, Awh, & Laurey, 2003) and higher-level conflict adaptation (Ullsperger, Bylsma, & Botvinick, 2005). The framework proposed by Egner (2014) highlights that the several factors that modulate conflict in the Stroop task include lower level components such as feature contingencies or stimulus-response associations (Bugg, 2014; Melara & Algom, 2003), and higher level strategic components (Logan, Zbrodoff, & Williamson, 1984).

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This framework is embodied in the widely accepted conflict-monitoring idea (Botvinick et al., 2001, 2004), especially the most recent iterations in which conflict-modulated Hebbian-learning operates at the level of each item (e.g., the words blue and yellow) rather than uniformly across all items within the experiment (i.e., Blais, Robidoux, Risko, & Besner, 2007; Blais & Verguts, 2012; Verguts & Notebaert, 2008) providing a comprehensive account of several effects by utilizing both top-down and bottom-up mechanisms.

Proportion congruency effects such as item-specific proportion congruency (ISPC) effect are often used to measure the top-down and bottom-up components of cognitive control. The ISPC effect refers to the fact that the Stroop effect can be modulated on an item-by-item basis such that within a single block of trials, individual stimuli that are mostly congruent show a larger Stroop effect than those that are mostly incongruent (Bugg, Jacoby, & Chanani, 2011; Bugg, Jacoby, & Toth, 2008; Jacoby, Lindsay, & Hessels, 2003; Jacoby, McElree, & Trainham, 1999). Bugg (2015) describes conditions under which the ISPC is mostly driven by top-down attentional settings reactively retrieved by item-specific control processes, in comparison to when it is driven by the bottom-up associative processes of contingency learning – conditions which map nicely onto the framework described by Egner (2014). Further support for an interaction between low-level and high-level processes is also demonstrated in Hutcheon and Spieler (2014) who show that the consistency, or lack thereof, of the association between stimulus features and conflict impacts whether conflict adaptation effects generalize across words in ISPC manipulations. It is interesting to point out that when contingency information is salient, even a neutral word (e.g., MOVE, TABLE) can show an ISPC-like pattern (Schmidt & Besner, 2008; Schmidt, Crump, Cheesman, & Besner, 2007). Because of this, Schmidt and colleagues argue that item-specific learning and sequential congruency effects are entirely bottom-up – there is no conflict to signal top-down mechanism. As an alternative to the conflict-monitoring idea, Schmidt (2013) proposed the parallel episodic processing model (PEP) which demonstrates that at least some control processes can be explained solely by implicit contingency learning, a low-level variation of stimulus-response (S-R) learning that relies on episodic memory.

The purpose of the current manuscript is to examine the extent to which contingency learning and conflict monitoring are related. The conflict-mediated Hebbian-learning hypothesis (i.e., Blais & Verguts, 2012; Blais et al., 2007; Verguts & Notebaert, 2008) makes the explicit claim that the control system is a conflict-reinforced learning system. That is, the ACC detects conflict and uses this to reinforce control on an item-by-item basis. Because the conflict-modulated Hebbian-learning model posits that contingency and conflict affect the same mechanism – the readjustment of attention on an item-by-item basis – it predicts that contingency and conflict will interact. In contrast, the PEP model (Schmidt, 2013) accounts for the control effects by appealing to memory storage and retrieval processes for the episodic memories of trials. Response conflict (i.e., congruency) occurs in this model at the response layer, but it does not feedback to any attentional system. This leads to the clear prediction that contingency and congruency should not interact, but instead produce additive effects.

To be clear, there are two major differences between the conflict-modulated Hebbian-learning (i.e., Blais & Verguts, 2012; Blais et al., 2007; Verguts & Notebaert, 2008) and the PEP model (Schmidt, 2013). First, the mechanism of learning is conceptually different. The former learns via strengthening of connection weights and the latter through episodic instances. For the purposes of this paper, this difference is not important for the performance of the models. The second difference is consequential. The conflict monitoring model states that the response conflict between the word and the color moderates how strongly associated a word and color become. When conflict is high, the association between the color and word is decreased because attention to the color is very high, effectively limiting how well the word is processed, thus predicting an interaction between the conflict and proportion contingency (Fig. 1a). Conversely, in Schmidt's (2013) PEP model, conflict is inconsequential to S-R learning, thus predicting only a main effect proportion contingency (Fig. 1b). To adjudicate between these competing models, we replicate and extend Schmidt et al. (2007) by adding a condition in which all stimulus words are incongruent.

## 2. Methods

### 2.1. Participants

For 0.80 power to detect an effect as small as 30 ms, we needed N > 120, 30 participants per cell. Therefore, a total of 146 English-speaking undergraduate students were recruited from Arizona State University's Introduction to Psychology research participation pool in exchange for course credit in accordance with the Institutional Review Board. The study required approximately one hour to complete.

### 2.2. Procedure

Subjects were randomly assigned to one of the four cells in the Proportion Contingent (50% vs. 75%) by Word Type (Conflict vs. Neutral) design. Subjects performed a Stroop task using the words BLUE, GREEN, ORANGE, RED, YELLOW in the conflict condition and replicating Schmidt et al. (2007) using MOVE, GRIP, SENT, FALL, BEAD in the neutral condition. The colors used in both conditions were blue, green, orange, red, and yellow. In the 50% condition, each word was presented in a certain color 50% of the time (60 trials per block) for the high contingency trials, and 16.67% of the time in three other colors (20 trials per block) for the low contingency trials. In the 75% condition, each word was presented in a certain color 75% of the time (90 trials per block) for the high contingency trials, and 8.33% of the time in three other color (10 trials per block) for the low contingency trials. It is important to note that in the conflict condition, this resulted in no word being presented in its corresponding color (i.e. $\text{BLUE}_{\text{BLUE}}$). The actual trial counts per cell are shown in Table 1.

Participants sat at a comfortable distance from the screen and keyboard within a small study cubicle in a room that allowed us to run as many as eight people at a time. Presentation of stimuli for the experiment was controlled by E-Prime 2.0 software (Psychology Software Tools, 2002). Each color was randomly mapped to the C, V, B, N and M keys then remained fixed for the duration of the experiment. The stimulus remained onscreen until the subject responded. A fixed inter-trial-interval (ITI) of 600 ms separated trials. The program was designed to repeat all incorrect and slow (RT > 3000 ms) trials at the end of a block until participants responded correctly or fast enough.[1] There were 8 blocks of trials presented, the first two blocks were practice blocks and were not analyzed. During this practice phase each of the response labels were presented on the screen in order corresponding to the response keys and feedback was provided in the form of a + or − symbol. This served as the fixation marker for the next trial. For the final six experimental blocks the response labels were removed from the screen and there was no feedback; a * was used as the fixation marker. Participants were still required to repeat any trial that was incorrect or responded to too slowly.[2]

## 3. Results

We excluded 26 participants from analysis for high errors, 18 of these responded to the word rather than the font color in the conflict

[1] After running the first 52 participants, it was found that 18 of the 26 people in the Conflict condition were responding to the word instead of responding to the color of the text. These 18 participants were excluded from analysis and an adjustment was made to the program.

[2] 5.40% of trials were repeated. This changed the proportion contingent manipulations, on average, by 0.48% in the 50% contingent condition, and 0.64% in the 75% contingent condition. A re-analysis of the data without the repeated trials included did not change the significance of the original analysis.

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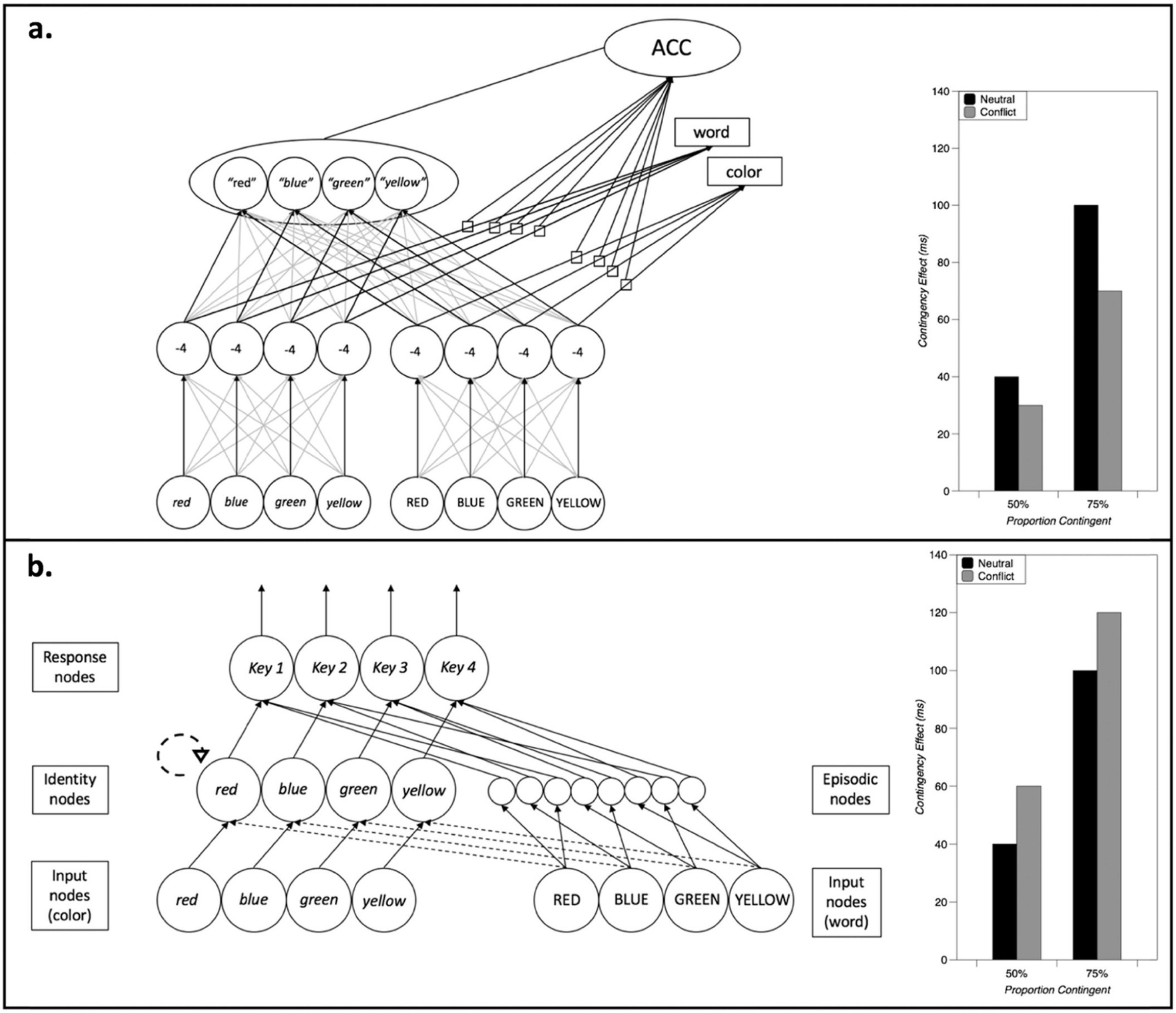


**Fig. 1.** This figure shows (a.) the conflict-modulated Hebbian-learning model from Blais et al. (2007) and its predictions for high conflict stimuli (see Blais et al., 2007 for more details). The bottom panel (b.) shows the parallel episodic processing model from Schmidt (2013) and its predictions for high conflict stimuli (see Schmidt, 2013 for more details).

condition, leaving a total of N = 120, divided into four cells (2 Proportion Contingent Conditions × 2 Word Type Conditions) of 30 participants each. Correct reaction times exceeding three (3) standard deviation units per subject, per cell were excluded resulting in the loss of 2.1% of correct reaction times (range: 0–4.3%). A 2 Proportion Contingent (75% vs. 50%) × 2 Word Type (Conflict vs. Neutral) × 2 Contingency (High vs. Low) mixed model MANOVA was conducted with response time (RT) and percent errors (PE) as dependent measures, and with proportion and word type as between-subjects factors and contingency as a within-subjects factor. We also report the partial eta-squared estimates for each of the univariate contributions (i.e., $\eta^2_{RT}$ and $\eta^2_{\%E}$) of the analysis.

There was a main effect of contingency such that low contingent items (887 ms; 8.3%) were slower and more error prone than high contingent items (819 ms; 4.9%; Fig. 2; Fig. 3), [$F(2, 115) = 145.1$, $p < 0.001$, $\eta^2 = 0.716$; $\eta^2_{RT} = 0.563$, $\eta^2_{\%E} = 0.628$]. There was also a main effect of word type such that conflict words (901 ms; 6.7%) were slower and more error prone (non-significant) than neutral words (805 ms; 6.5%), [$F(2115) = 5.2$, $p = 0.007$, $\eta^2 = 0.082$; $\eta^2_{RT} = 0.080$, $\eta^2_{\%E} < 0.001$]. There was a contingency by proportion interaction such that the contingency effect was larger in the 75% proportion condition (99 ms; 4.6%) than in the 50% proportion condition (37 ms; 2.1%) [$F(2115) = 25.2$ $p < 0.001$, $\eta^2 = 0.304$; $\eta^2_{RT} = 0.216$, $\eta^2_{\%E} = 0.195$]. Critically, there was a contingency by word type interaction (Fig. 2; Fig. 3) such that the size of the contingency effect was smaller for conflict words (52 ms; 2.7%) than for neutral words (84 ms; 4.0%) [$F(2115) = 6.5$, $p = 0.002$, $\eta^2 = 0.101$; $\eta^2_{RT} = 0.068$, $\eta^2_{\%E} = 0.056$]. There was also a three-way interaction (Fig. 2; Fig. 3) indicating that the reduction in the size of the contingency effect for neutral vs conflict words in the 75% proportion condition was larger (48 ms; 2.38%) than the reduction in the size of the contingency effect for neural vs. conflict words in the in the 50% condition (16 ms; 0.15%) [$F(2115) = 3.23$, $p = 0.043$, $\eta^2 = 0.053$; $\eta^2_{RT} = 0.018$, $\eta^2_{\%E} = 0.043$].

## 4. Discussion

The primary goal of this paper was to test the claim that contingency learning is independent from response conflict (Schmidt, 2013; Schmidt & Besner, 2008). We replicated and extended Schmidt et al. (2007) by assessing whether response conflict impacted the size of the

**Table 1**
An illustration of color-word pairings for each of the four conditions in one block of the experiment. All word-color pairings were randomly created for each subjects at the start of the experiments and remained fixed thereafter with the constraint that no word was ever paired with its color (i.e., there were no congruent trials).

| | Color | | | | |
|---|---|---|---|---|---|
| Word | Blue | Green | Orange | Red | Yellow |
| 50% contingency neutral condition | | | | | |
| MOVE | 0 | 4 | 4 | 4 | 12 |
| GRIP | 12 | 0 | 4 | 4 | 4 |
| SENT | 4 | 12 | 0 | 4 | 4 |
| FALL | 4 | 4 | 12 | 0 | 4 |
| BEAD | 4 | 4 | 4 | 12 | 0 |
| 75% contingency neutral condition | | | | | |
| MOVE | 0 | 2 | 2 | 2 | 18 |
| GRIP | 18 | 0 | 2 | 2 | 2 |
| SENT | 2 | 18 | 0 | 2 | 2 |
| FALL | 2 | 2 | 18 | 0 | 2 |
| BEAD | 2 | 2 | 2 | 18 | 0 |
| 50% contingency conflict condition | | | | | |
| BLUE | 0 | 4 | 4 | 4 | 12 |
| GREEN | 12 | 0 | 4 | 4 | 4 |
| ORANGE | 4 | 12 | 0 | 4 | 4 |
| RED | 4 | 4 | 12 | 0 | 4 |
| YELLOW | 4 | 4 | 4 | 12 | 0 |
| 75% contingency conflict condition | | | | | |
| BLUE | 0 | 2 | 2 | 2 | 18 |
| GREEN | 18 | 0 | 2 | 2 | 2 |
| ORANGE | 2 | 18 | 0 | 2 | 2 |
| RED | 2 | 2 | 18 | 0 | 2 |
| YELLOW | 2 | 2 | 2 | 18 | 0 |

contingency learning effect (Fig. 2; Fig. 3). Conflict was incorporated into the task by using all incongruent items such that one incongruent word was most likely for each color, and varied the strength of that contingency (i.e., 50% versus 75%). Consistent with the conflict-mediated Hebbian learning account, we observed that the size of the contingency effect was reduced when conflict present.

In the neutral word condition, the word co-occurs with the color and does not generate a task-relevant response. Nonetheless an association is created between the color of the text and the appropriate response. In the conflict word condition, the irrelevant word generates a task-relevant response that must be suppressed in order to perform the task. In the model activation of this word is suppressed (mathematically indistinguishable from increased activation of the color) and this causes a reduction in the strength of the S-R association in the conflict condition.

This counterintuitive explanation for a reduction in the size of the contingency effect as conflict increases (Fig. 2; Fig. 3) is consistent with the strength of association account of the Stroop effect. MacLeod and Dunbar (1988) showed that when the subject is shown abstract shapes and asked to respond to them by saying a color word, a specific

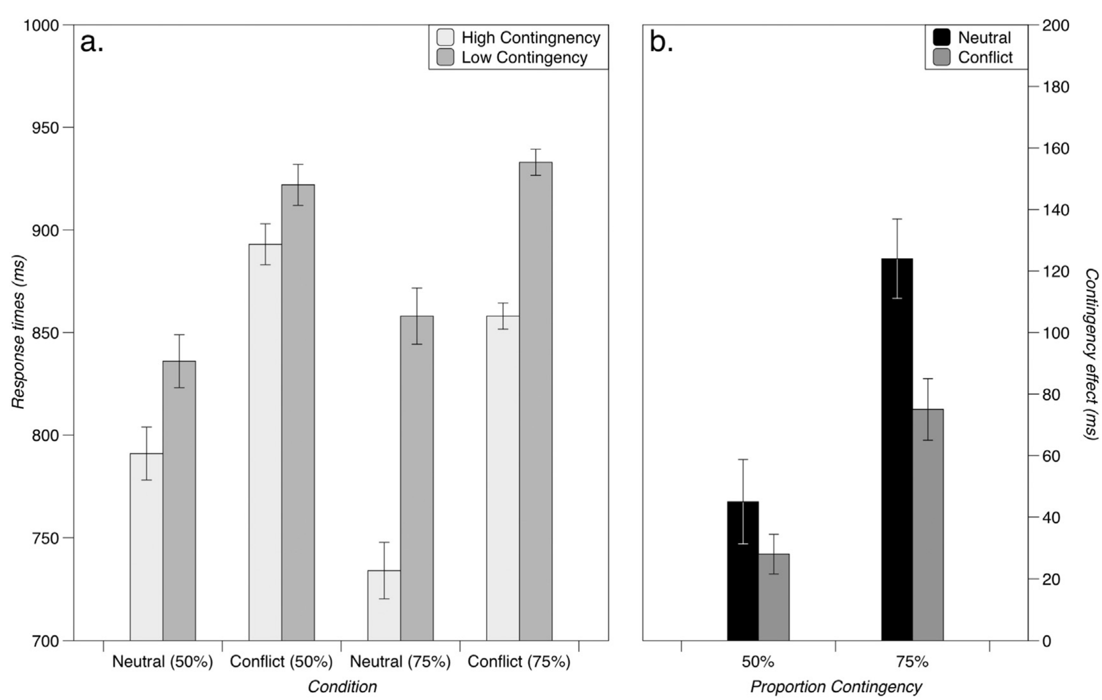


**Fig. 2.** The left panel (a.) shows mean response time using milliseconds (ms) for high contingency and low contingency stimuli in each of the four cells. The right panel (b.) shows the contingency effect (low contingency - high contingency) for each of the four cells. The behavioral data in the right panel qualitatively match the predictions of the conflict-mediated Hebbian-learning model found in Fig. 1b. Error bars indicate the mean squared error.

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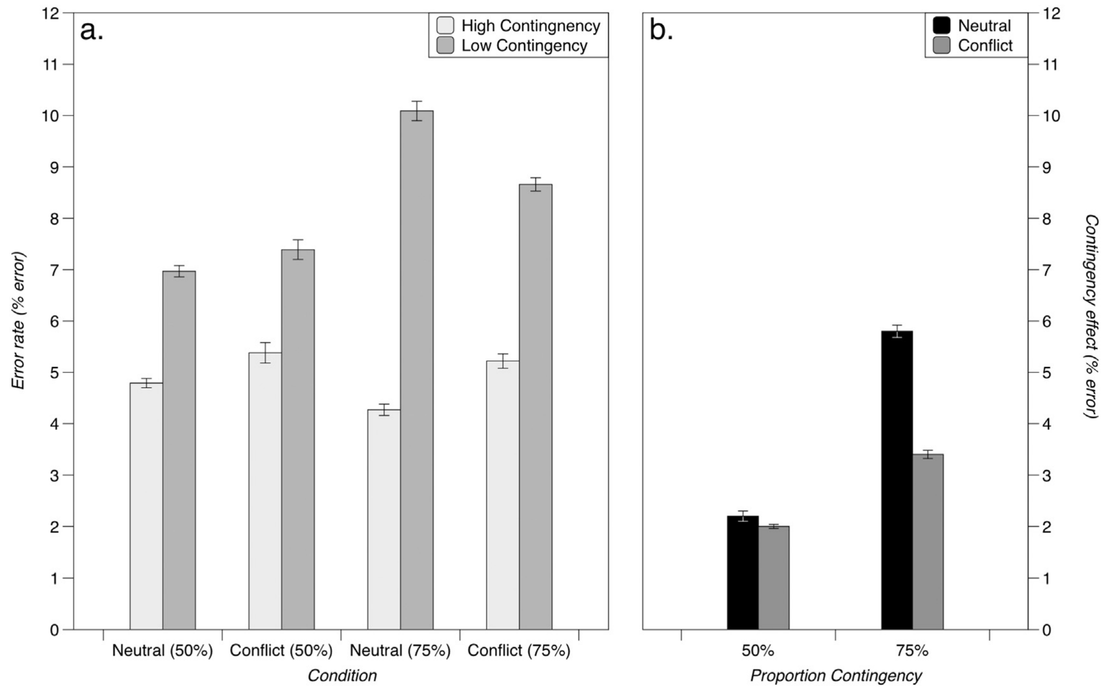


**Fig. 3.** The left panel (a.) shows mean error rates (%) for high contingency and low contingency stimuli in each of the four cells. The right panel (b.) shows the contingency effect (low contingency - high contingency) for each of the four cells. Error bars indicate the mean squared error.

pattern emerged with practice. Early on, the color of the shape interfered with their ability to say its name, but the name of the shape did not interfere with their ability to name its color. After several hundred trials, the irrelevant dimension interfered on both the shape naming and color naming tasks. Finally, after a few thousand trials, the color of the shape no longer interfered with their ability to say its name, but now the name of the shape did interfere with their ability to name its color. This early demonstration is also important because it shows that a stimulus that is initially not associated with a response can become more strongly associated with that response than the original stimulus. It also questions whether the neutral stimuli from Schmidt et al. (2007) are truly free from conflict by the end of the experiment.[3]

Although the PEP model explicitly states that conflict and contingency learning are the result of independent mechanisms, the reduced contingency effect we observed for the high-conflict trials could arise if we assume that attentional settings learned during the practice block are implemented prior to the start of the experiment blocks. To be clear, adding this mechanism to the PEP model would effectively turn it into the Hebbian learning model in which the learning rate parameter lambda is set to change very slowly over time. The clear prediction from this adjusted PEP model and the Hebbian learning model is that the size of the contingency effect should grow less rapidly for conflict items than for neural items. Exactly this pattern of results is observed in our data and is shown in Fig. 4.

These findings are readily explained within the framework proposed by Egner (2014). In this multiple-levels framework, the addition of conflict to a given paradigm would also interact with a contingency learning effect. This would occur because the simple S-R associations and perceptual information that are encoded into an event file (Hommel, 1998) include the incongruency between the word and color. In Egner (2014), once the stimulus triggers the retrieval of the dynamic event file from memory, the level which the response to the stimulus is mediated at is controlled by a preferential system that processes the stimuli at the lowest level necessary to make an accurate response. Egner argues that this explains why the sequential congruency effect appears to be driven by S-R learning in some paradigms and conflict adaptation in others. This framework highlights that both contingency learning and higher level control processes contribute to performance.

The explanation of performance offered by Egner (2014) is similar to the dual item-specific mechanism account (Bugg, 2015). Her account expands on the Hebbian-learning idea by explicitly stating the conditions under which contingency learning mechanisms vs. item-specific control mechanisms will dominate performance. According to this hypothesis it is the relative salience of the irrelevant dimension (i.e., the word in a Stroop task) versus the relevant dimension (i.e., color) that determines the relative contribution of contingency learning vs. item-specific mechanisms of control. When attention is captured by the irrelevant dimension the ISPC effect is primarily driven by contingency learning mechanisms, but when attention is captured by the relevant dimension the ISPC effect is primarily driven by item-specific control mechanisms which trigger retrieval of top-down attentional settings. This framework would therefore explain the reduction in learning for conflict words compared to neutral words in much the same way as the Hebbian learning account: attention is captured more by a conflict word than a neutral word.

These results are also consistent with recent work showing that response conflict impairs the formation of associations in reinforcement learning. Cavanagh, Masters, Bath, and Frank (2014) reported a Simon task in which correct responses were given small rewards but incorrect responses were given large punishments. They reported that reinforcement learning was impaired with the introduction of conflict in the training stage, showing that there was a cost of conflict in the creation of the S-R binding. Using electrophysiological and genetic measurements, they also found that interactive corticostriatal systems modulate reinforcement learning values as a function of conflict. Both these and our results clearly demonstrate response conflict and contingency learning are tightly integrated.

The current theoretical assertion that response-conflict and contingency learning interact in cognitive control may also generalize to other forms of conflict. Task-conflict is well documented in the behavioral (Entel, Tzelgov, Bereby-Meyer, & Shahar, 2015; Kalanthroff, Goldfarb, & Henik, 2013) and neuroimaging (Aarts, Roelofs, & van

[3] The claim is not that MOVE and BLUE now share a meaningful semantic connection, as do WATER and BLUE. Rather, the claim is that they become associated at the response level which is rather obvious given the effect that Schmidt et al. (2007) describe.

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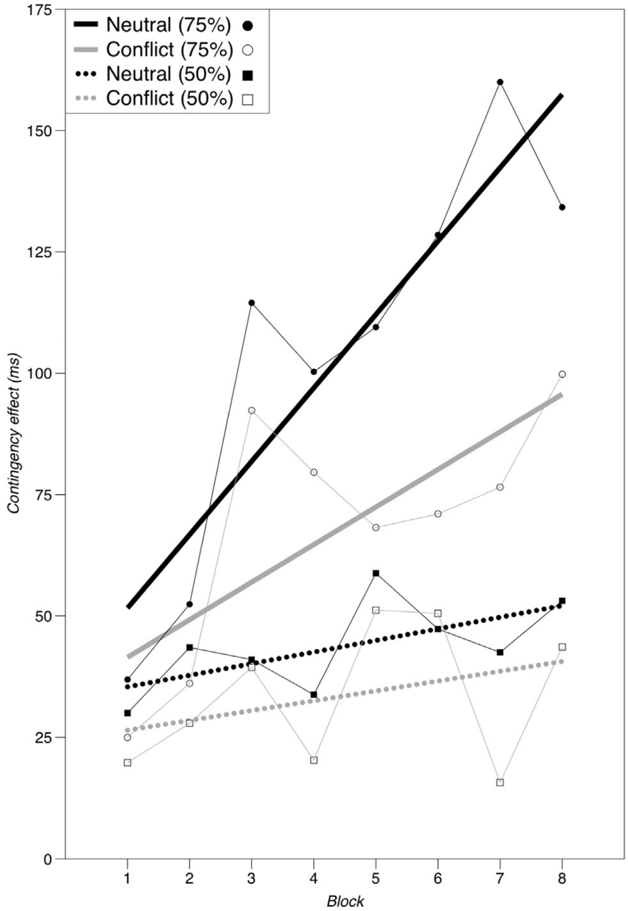


**Fig. 4.** The graph shows the contingency effect as a function of the block (including practice blocks 1 and 2) for each of the four cells. The large increase in the size of the contingency effect at Block 3 marks the start of experimental trials when subjects no longer had the response labels displayed on the bottom of the screen. Note that the slope of the best fitting linear function is smaller for conflict trials compared to neutral trials, especially when the contingency is strong.

Turennout, 2009; Bench et al., 1993; Steinhauser & Hübner, 2009) literature. It is hypothesized to occur when there is perceptual information that affects response selection, but unlike response conflict, the two perceptual domains do not activate two competing informational concepts (i.e. the word RED and color red are conceptually associated). Rather task conflict is simply the competition that arises from having to suppress the reading task that is automatically activated. It is important to note that task-conflict and response-conflict both contribute to the Stroop effect (Goldfarb & Henik, 2007; MacLeod & MacDonald, 2000; see Melara & Algom, 2003 for an alternative account of the Stroop effect).

A recent study by Levin and Tzelgov (2016) showed that increasing the amount of task conflict interacted with the magnitude of the contingency learning effect. They replicated the neutral word condition from Schmidt et al. (2007) and then removed task-conflict using shapes instead of words in a separate condition. They argued that this removes all sources of conflict, including task conflict, creating a truly neutral ("conflict-free") condition. There was a significant interaction between contingency learning and their different conflict conditions, such that the contingency learning effect was smaller for the task-conflict neutral-word condition than for the task-conflict free shape condition. Levin and Tzelgov (2016) argue that these results show that contingency learning is independent from conflict because the conflict-free shape condition also showed contingency learning. To be entirely clear, Levin and Tzelgov (2016) report the same general pattern as the one reported here. Whereas we show that response conflict reduces the magnitude of the contingency effect, they show that task conflict reduces the magnitude of the contingency effect. Thus it appears that other forms of conflict may also be tightly coupled with contingency learning.

## 5. Conclusion

The conflict-mediated Hebbian-learning account (Blais et al., 2007; Verguts & Notebaert, 2008) suggests that cognitive control is the result of many top-down and bottom-up processes, such as conflict adaptation and contingency learning respectively, that strongly influence each other. Conversely, Schmidt (2013) argues that behavioral effects believed to be products of a control system, such as the item-specific proportion congruency effect, can be explained solely by bottom-up processes such as contingency learning. To determine whether these factors influence each other, we replicated and extended Schmidt et al. (2007) to show that contingency learning is indeed affected by response conflict thereby questioning the utility of the parallel episodic processing framework as a complete account of the item-specific proportion congruency effect. There is now overwhelming support for the notion that top-down and bottom-up mechanisms contribute to cognitive control. Future research on cognitive control should aim to determine how these mechanisms are integrated.

## References

Aarts, E., Roelofs, A., & van Turennout, M. (2009). Attentional control of task and response in lateral and medial frontal cortex: Brain activity and reaction time distributions. *Neuropsychologia*, *47*(10), 2089–2099.

Bench, C. J., Frith, C. D., Grasby, P. M., Friston, K. J., Paulesu, E., Frackowiak, R. S., & Dolan, R. J. (1993). Investigations of the functional anatomy of attention using the Stroop test. *Neuropsychologia*, *31*(9), 907–922.

Blais, C., & Verguts, T. (2012). Increasing set size breaks down sequential congruency: Evidence for an associative locus of cognitive control. *Acta Psychologica*, *141*(2), 133–139.

Blais, C., Robidoux, S., Risko, E. F., & Besner, D. (2007). Item-specific adaptation and the conflict-monitoring hypothesis: A computational model. *Psychological Review*, *114*(4), 1076–1086.

Blais, C., Stefanidi, A., & Brewer, G. A. (2014). The Gratton effect remains after controlling for contingencies and stimulus repetitions. *Frontiers in Psychology*, *5* http://doi.org/10.3389/fpsyg.2014.01207.

Botvinick, M. M., Braver, T. S., Barch, D. M., Carter, C. S., & Cohen, J. D. (2001). Conflict monitoring and cognitive control. *Psychological Review*, *108*(3), 624–652.

Botvinick, M. M., Cohen, J. D., & Carter, C. S. (2004). Conflict monitoring and anterior cingulate cortex: An update. *Trends in Cognitive Sciences*, *8*(12), 539–546.

Brown, J. W., & Braver, T. S. (2005). Learned predictions of error likelihood in the anterior cingulate cortex. *Science*, *307*(5712), 1118–1121.

Bugg, J. M. (2014). Conflict-triggered top-down control: Default mode, last resort, or no such thing? *Journal of Experimental Psychology. Learning, Memory, and Cognition*, *40*(2), 567–587.

Bugg, J. M. (2015). The relative attractiveness of distractors and targets affects the coming and going of item-specific control: Evidence from flanker tasks. *Attention, Perception, & Psychophysics*, *77*(2), 373–389.

Bugg, J. M., Jacoby, L. L., & Toth, J. P. (2008). Multiple levels of control in the Stroop task. *Memory & Cognition*, *36*(8), 1484–1494.

Bugg, J. M., Jacoby, L. L., & Chanani, S. (2011). Why it is too early to lose control in accounts of item-specific proportion congruency effects. *Journal of Experimental Psychology. Human Perception and Performance*, *37*(3), 844–859.

Cavanagh, J. F., Masters, S. E., Bath, K., & Frank, M. J. (2014). Conflict acts as an implicit cost in reinforcement learning. *Nature Communications*, *5*, 5394.

Cohen, J. D., Dunbar, K., & McClelland, J. L. (1990). On the control of automatic processes: A parallel distributed processing account of the Stroop effect. *Psychological Review*, *97*(3), 332–361.

Egner, T. (2014). Creatures of habit (and control): A multi-level learning perspective on the modulation of congruency effects. *Frontiers in Psychology*, *5*, 1247.

Entel, O., Tzelgov, J., Bereby-Meyer, Y., & Shahar, N. (2015). Exploring relations between task conflict and informational conflict in the Stroop task. *Psychological Research*, *79*(6), 913–927.

Goldfarb, L., & Henik, A. (2007). Evidence for task conflict in the Stroop effect. *Journal of Experimental Psychology. Human Perception and Performance*, *33*(5), 1170–1176.

Gratton, G., Coles, M. G., & Donchin, E. (1992). Optimizing the use of information: Strategic control of activation of responses. *Journal of Experimental Psychology. General*, *121*(4), 480–506.

Grinband, J., Savitskaya, J., Wager, T. D., Teichert, T., Ferrera, V. P., & Hirsch, J. (2011). The dorsal medial frontal cortex is sensitive to time on task, not response conflict or error likelihood. *NeuroImage*, *57*(2), 303–311.

Hommel, B. (1998). Event files: Evidence for automatic integration of stimulus-response episodes. *Visual Cognition*, *5*(1–2), 183–216.

Hutcheon, T. G., & Spieler, D. H. (2014). Contextual influences on the sequential congruency effect. *Psychonomic Bulletin & Review*, *21*(1), 155–162.

Jacoby, L. L., McElree, B., & Trainham, T. N. (1999). Automatic influences as accessibility bias in memory and Stroop-like tasks: Toward a formal model. In A. Koriat, & D. Gopher (Eds.), *Cognitive regulation of performance: Interaction of theory and application. Vol. XVII*, . Cambridge: MIT Press.

Jacoby, L. L., Lindsay, D. S., & Hessels, S. (2003). Item-specific control of automatic processes: Stroop process dissociations. *Psychonomic Bulletin & Review*, *10*(3), 638–644.

Kalanthroff, E., Goldfarb, L., & Henik, A. (2013). Evidence for interaction between the stop signal and the stroop task conflict. *Journal of Experimental Psychology. Human Perception and Performance*, *39*(2), 579–592.

Levin, Y., & Tzelgov, J. (2016). Contingency learning is not affected by conflict experience: Evidence from a task conflict-free, item-specific Stroop paradigm. *Acta Psychologica*, *164*, 39–45.

Logan, G. D. (1988). Toward an instance theory of automatization. *Psychological Review*, *95*(4), 492–527.

Logan, G. D., Zbrodoff, N., & Williamson, J. (1984). Strategies in the color-word Stroop task. *Bulletin of the Psychonomic Society*, *22*(2), 135–138.

MacDonald, A. W., Cohen, J. D., Stenger, V. A., & Carter, C. S. (2000). Dissociating the role of the dorsolateral prefrontal and anterior cingulate cortex in cognitive control. *Science*, *288*(5472), 1835–1838.

MacLeod, C. M., & Dunbar, K. (1988). Training and Stroop-like interference: Evidence for a continuum of automaticity. *Journal of Experimental Psychology. Learning, Memory, and Cognition*, *14*(1), 126–135.

MacLeod, C. M., & MacDonald, P. A. (2000). Interdimensional interference in the Stroop effect: Uncovering the cognitive and neural anatomy of attention. *Trends in Cognitive Sciences*, *4*(10), 383–391.

Mayr, U., Awh, E., & Laurey, P. (2003). Conflict adaptation effects in the absence of executive control. *Nature Neuroscience*, *6*(5), 450–452.

Melara, R. D., & Algom, D. (2003). Driven by information: A tectonic theory of Stroop effects. *Psychological Review*, *110*(3), 422–471.

Rabbitt, P. (1966). Errors and error correction in choice-response tasks. *Journal of Experimental Psychology*, *71*(2), 264–272.

Schmidt, J. R. (2013). The parallel episodic processing (PEP) model: Dissociating contingency and conflict adaptation in the item-specific proportion congruent paradigm. *Acta Psychologica*, *142*(1), 119–126.

Schmidt, J. R., & Besner, D. (2008). The stroop effect: Why proportion congruent has nothing to do with congruency and everything to do with contingency. *Journal of Experimental Psychology. Learning, Memory, and Cognition*, *34*(3), 514–523.

Schmidt, J. R., & de Houwer, J. (2011). Now you see it, now you don't: Controlling for contingencies and stimulus repetitions eliminates the Gratton effect. *Acta Psychologica* http://doi.org/10.1016/j.actpsy.2011.06.002.

Schmidt, J. R., Crump, M. J. C., Cheesman, J., & Besner, D. (2007). Contingency learning without awareness: Evidence for implicit control. *Consciousness and Cognition*, *16*(2), 421–435.

Steinhauser, M., & Hübner, R. (2009). Distinguishing response conflict and task conflict in the Stroop task: Evidence from ex-Gaussian distribution analysis. *Journal of Experimental Psychology. Human Perception and Performance*, *35*(5), 1398–1412.

Stroop, J. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology*, *18*, 643–662.

Ullsperger, M., Bylsma, L., & Botvinick, M. M. (2005). The conflict adaptation effect: It's not just priming. *Cognitive, Affective, & Behavioral Neuroscience*, *5*(4), 467–472.

Verguts, T., & Notebaert, W. (2008). Hebbian learning of cognitive control: Dealing with specific and nonspecific adaptation. *Psychological Review*, *115*(2), 518–525.

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