Journal of Experimental Psychology:
Learning, Memory, and Cognition
2016, Vol. 42, No. 9, 1496–1505

0278-7393/16/$12.00 http://dx.doi.org/10.1037/xlm0000254

COMMENTARY

Proportion Congruency and Practice: A Contingency Learning Account of Asymmetric List Shifting Effects

James R. Schmidt
Ghent University

Performance is impaired when a distracting stimulus is incongruent with the target stimulus (e.g., "green" printed in red). This congruency effect is decreased when the proportion of incongruent trials is increased, termed the proportion congruent effect. This effect is typically interpreted in terms of the adaptation of attention in response to conflict. In contrast, the contingency account argues that the effect is driven by the learning of predictive relationships between words and responses. In a recent report, Abrahamse, Duthoo, Notebaert, and Risko (2013) demonstrated larger changes in the magnitude of the proportion congruent effect when switching from a mostly congruent list to a mostly incongruent list, relative to the reverse order. They argued that this asymmetric list shifting effect fits only with the conflict adaptation perspective. However, the current paper presents reanalyses of this data and an adaptation of the Parallel Episodic Processing model that together demonstrate how the contingency account can explain these findings equally well when considering the generally accepted notion that performance improves with practice. The contingency account may still be the most parsimonious view.

Keywords: proportion congruent effects, conflict adaptation, contingency learning, practice, attention capture

When participants are asked to attend to one dimension of a multidimensional stimulus they are only partially successful in doing so. For instance, in the Stroop task (Stroop, 1935) participants are presented with colored color words, and are asked to ignore the word and identify the print color. Performance is worse on incongruent (e.g., "green" in red) relative to congruent trials (e.g., "green" in green). This *congruency effect* is reduced the higher the percentage of incongruent trials in the task (Lowe & Mitterer, 1982). This *proportion congruent* (PC) *effect* is generally interpreted as evidence that participants decrease attention to the distracter in response to the frequent conflict in the mostly incongruent condition (e.g., see Botvinick, Braver, Barch, Carter, & Cohen, 2001; Cheesman & Merikle, 1986; Cohen, Dunbar, & McClelland, 1990; Lindsay & Jacoby, 1994). This attentional modulation explanation of the PC effect is called the *conflict adaptation* (or *conflict monitoring*) *account.*

The conflict adaptation account has not gone unchallenged, however. Schmidt presented the argument that PC effects are, instead, the result of simple contingency learning processes (Schmidt, 2013c; Schmidt & Besner, 2008; Schmidt, Crump, Cheesman, & Besner, 2007; see Schmidt, 2013a for a detailed review). The *contingency account* argues that there are predictive relationships between the words and responses that bias the mostly congruent and mostly incongruent conditions differently. In the mostly congruent condition, the word is predictive of the congruent response (e.g., "green" is presented most often in green). In the mostly incongruent condition, the word is (depending on design) either (a) unpredictive (i.e., presented equally often in all colors), or (b) strongly predictive of an *incongruent* response (e.g., "yellow" is presented most often in blue). The result of these contingency biases is a smaller congruency effect in the mostly incongruent condition.

Though there is no clear agreement on which account provides the best explanation of the PC effect (e.g., Blais & Bunge, 2010; Bugg & Hutchison, 2013; Bugg, Jacoby, & Chanani, 2011; Crump & Milliken, 2009; Shedden, Milliken, Watter, & Monteiro, 2013), there are some pieces of evidence which provide compelling support for the contingency account (e.g., Atalay & Misirlisoy, 2012; Grandjean et al., 2013; Hazeltine & Mordkoff, 2014; Schmidt, 2013c). For instance, Schmidt (2013c) presents a dissociation procedure in which contingencies and PC could be separately assessed. Highly reliable contingency effects were observed, but (contingency-unbiased) PC effects were not observed (see also, Hazeltine & Mordkoff, 2014). At least for the "item-specific" PC task that was used (see Jacoby, Lindsay, & Hessels, 2003), such results seem to argue strongly against the conflict adaptation account, as the conflict adaptation account should have predicted the reverse observations.

James R. Schmidt is funded by a postdoctoral researcher grant (1211814N) of the Research Foundation–Flanders (FWO–Vlaanderen). I thank Elger Abrahamse for providing the data for the reanalysis in Analysis 1 and his useful thoughts on this work.

Correspondence concerning this article should be addressed to James R. Schmidt, Department of Experimental Clinical and Health Psychology, Ghent University, Henri Dunantlaan 2, B-9000 Ghent, Belgium. E-mail: james.schmidt@ugent.be

Asymmetric List Shifting

Other findings, however, have been argued to provide evidence of conflict adaptation, separate from contingency biases. For instance, if PC is manipulated with some contingency-biased inducer items, a PC effect is still observed for intermixed contingency-unbiased diagnostic items in some scenarios (e.g., Bugg & Hutchison, 2013; Hutchison, 2011; Wühr, Duthoo, & Notebaert, 2015). A competing temporal learning (i.e., rhythmic timing) account has been shown to provide an equally viable account of such effects, however (Schmidt, 2013b, 2014b; Schmidt, Lemercier, & De Houwer, 2014; see also, Schmidt, 2014a).

Of particular interest for present purposes, another line of evidence for conflict adaptation in the PC effect was presented by Abrahamse et al. (2013), which might initially seem to allow for *no* alternative nonconflict learning interpretation. They demonstrated what they referred to as an *asymmetric list shifting effect*. In their Experiment 1a, for instance, half of the participants started with a mostly congruent block of trials, and then switched to a mostly incongruent block (MC-MI). The other half of participants received the reverse order (MI-MC). The stimulus frequencies are presented in Table 1. The *decrease* in the congruency effect from the first to second block for MC-MI participants exceeded the *increase* for the MI-MC participants.

Abrahamse et al. (2013) argued that this *asymmetric* list shifting effect provides evidence for conflict adaptation. Specifically, in the MC-MI group participants start out with relatively lax attention in the initial mostly congruent block, producing a large congruency effect, but then rapidly adapt to the following mostly incongruent block. Thus, a sizable decrease in the congruency effect occurs. In contrast, participants in the MI-MC condition rigorously direct attention away from the word in the initial mostly incongruent block, resulting in a small congruency effect. Due to this decreased attention to the word, they either (a) do not notice the change in PC or (b) do not adjust their strategy when the mostly congruent block begins. Thus, the change in the congruency effect is small.

Abrahamse et al. (2013) also argue that the simplest version of the contingency account is not consistent with the asymmetric list shifting effect. According to this argument, if participants are only responsive to the local contingencies, then the decrease in the congruency effect from the mostly congruent to mostly incongruent block should be roughly symmetric with the increase from mostly incongruent to mostly congruent. Indeed, they note that there was little evidence at all of a change in the congruency effect in the MI-MC condition, which seems inconsistent with the contingency learning perspective, at least in its simplest form. How, then, can these results be reconciled with those of Schmidt (2013c) and Hazeltine and Mordkoff (2014), which demonstrated very clear support for the contingency account using similar stimulus frequencies? It additionally seems unlikely that a temporal learning account could explain the asymmetric list shifting effect, so the list shifting effect seems particularly interesting and worthy of further consideration.

Table 1
Experiment 1 Stimulus Pairings (Abrahamse et al., 2013)

	Mostly congruent				Mostly incongruent			
Colors	Red	Green	Yellow	Blue	Red	Green	Yellow	Blue
Red	54	6	6	6	18	18	18	18
Green	6	54	6	6	18	18	18	18
Yellow	6	6	54	6	18	18	18	18
Blue	6	6	6	54	18	18	18	18

Practice Effects

It is well known that performance is not stable over time in response time experiments. For instance, participants respond slower overall early on in an experiment, and then rapidly improve in performance in a decelerating function (Logan, 1988; Newell & Rosenbloom, 1981). In blocked data, this can be represented in a power function (or in more fine-grained trial-by-trial data, an exponential function; see Heathcote, Brown, & Mewhort, 2000; Myung, Kim, & Pitt, 2000). As Logan puts it (1988), “The power-function speed-up has been accepted as a nearly universal description of skill acquisition to such an extent that it is treated as a law, a benchmark prediction that theories of skill acquisition must make to be serious contenders” (p. 495). Thus, it is reasonable to assume that performance in earlier blocks will be worse than performance in later blocks.

More importantly, it is also well known that, in addition to general speedups across blocks in Stroop tasks, congruency effects similarly decay over practice (e.g., Dulaney & Rogers, 1994; Ellis & Dulaney, 1991; MacLeod, 1998; Simon, Craft, & Webster, 1973; Stroop, 1935). This can, itself, be a by-product of the power function: Both congruent and incongruent trial performance will rapidly improve, but incongruent trials stand to gain more (i.e., incongruent trials are slower to start out with). This decrease in the congruency effect over time has important implications for asymmetric list shifting effects. In the MC-MI condition, the contingency account predicts a decrease from Block 1 to Block 2 because of the change in the contingencies, and this will be complimented by the practice benefit. Thus, a very large list shift effect should be expected. In contrast, in the MI-MC list the contingency account predicts an *increase* in the congruency effect from Block 1 to Block 2, but this will be counteracted by the general *decrease* in congruency effects observed with practice. Thus, a net change in the congruency effect will be small or absent, potentially even reversed (i.e., if the decrease from practice exceeds the increase from contingency biases).

As the above analysis shows, contingency and practice effects complement each other in the MC-MI list, but counteract each other in the MI-MC list, potentially explaining the asymmetry in list shifting. Abrahamse et al. (2013) did acknowledge the above concerns. In order to rule out this argument, their Experiment 1b had participants perform the *same* PC list for two blocks, either MC-MC or MI-MI. The authors report that the congruency effect did not significantly decrease in either condition, and concluded that decreases in the congruency effect over blocks was not an issue. However, the congruency effect was numerically reduced by about 27 ms in both the MC-MC and MI-MI conditions. Thus, the role of practice in list shifting cannot be easily discarded based on this null finding.

Indeed, Abrahamse et al. (2013) further reported an analysis aimed to control for practice. In this analysis, the two experiments were compared, using the MC-MC condition of Experiment 1b as a control for the MC-MI condition and the MI-MI condition as a control for the MI-MC condition. An experiment (Experiment 1a vs. Experiment 1b) by block (Block 1 vs. Block 2) by order (MC-MI/MC-MC vs. MI-MC/MI-MI) by congruency (congruent vs. incongruent) analysis of variance (ANOVA) revealed a significant four-way interaction, which was interpreted as indicating that the asymmetric list shifting effect is more than just practice. Unfortunately, this was not the correct control analysis, because in Block 2 *mostly incongruent* trials in the MC-MI condition are treated as being identical to *mostly congruent* trials in the MC-MC condition, and the reverse is true for the MI-MC/MI-MI order. Thus, this analysis also fails to convincingly rule out practice effects on list shifting.

Analysis 1: Experiment 1 Reanalysis

A more appropriate control for practice would be to conduct an experiment (Experiment 1a vs. Experiment 1b) by block (Block 1 vs. Block 2) by *PC* (mostly congruent vs. mostly incongruent) by congruency (congruent vs. incongruent) ANOVA. This is likely the control Abrahamse et al. (2013) intended to test. If there is more to the list shifting effect of Experiment 1a than the simple practice effects observed in Experiment 1b, then the Experiment × Block × Congruency × PC interaction should be significant. That is, in the various blocks of mostly congruent and mostly incongruent trials, congruency effects should differ in systematic ways between Experiment 1a and Experiment 1b.

Unfortunately, this interaction cannot be tested with a simple ANOVA, because the cells that are manipulated between-groups vary in the two experiments (e.g., PC is manipulated between-groups in Experiment 1b, but not in Experiment 1a). An ANOVA cannot accommodate this sort of *unbalanced* design. However, a linear mixed effects (LME) model can. For readers unfamiliar with LME models, the test described in the Method section below is essentially identical to a typical ANOVA, except with an unbalanced dataset.

Method

In order to control for practice effects on the asymmetric list shifting effect, an LME model was conducted with the MIXED command in SPSS, with restricted likelihood estimation. Participants were entered as a random factor, congruency and block were entered as repeated factors with a compound symmetry variance structure. Experiment, block, congruency, and PC were then introduced in a factorial design. The same trimming procedures were used as in the original report. That is, response times were trimmed if (a) the response given was incorrect and/or (b) the response time (RT) exceeded three standard deviations from the mean RT for that participant in that cell of the design.

Results

Response times. The response time data for Experiments 1a and 1b are presented in Figures 1a and 1c, respectively. The full results of the LME are presented in Table 2. Most notably, the critical four-way interaction between experiment, block, congruency, and PC was not significant. Thus, there was no evidence of an asymmetric list shifting effect independent of practice benefits. In fact, dropping the experiment factor from the LME results in better model fit (using maximum likelihood estimation; Akaike information criterion (AIC) = 2,126; Bayesian information criterion [BIC] = 2,158) than the model with the experiment factor (AIC = 2,130; BIC = 2,186). In other words, there was no evidence that the two experiments differed in any meaningful way. Note that there *was* a main effect of block, indicating that responses were faster in the second block. There was also a marginal interaction between block and congruency, indicating that the congruency effect was smaller in Block 2. Thus, evidence for practice effects is present in the Experiment 1 data.

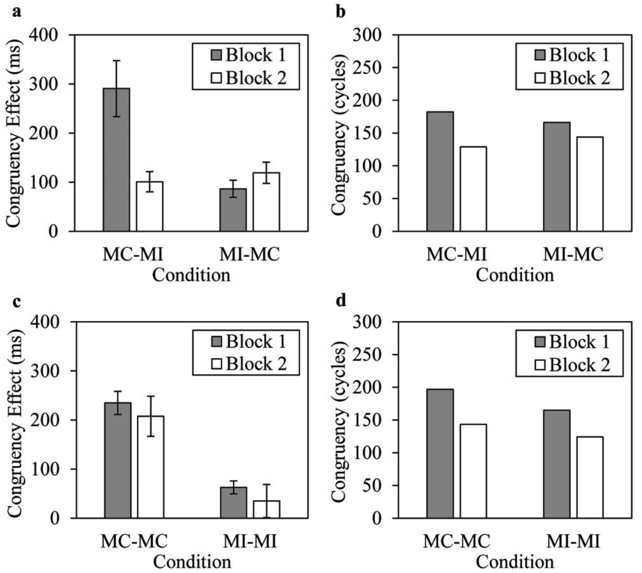

Figure 1. Experiment 1a (a) response times and (b) model cycle times, and Experiment 1b (c) response times and (d) model cycle times for Abrahamse et al. (2013). MC = mostly congruent; MI = mostly incongruent.

Percentage error. The percentage error data of Experiments 1a and 1b are presented in Figures 2a and 2c, respectively. The full results of the LME are presented in Table 3. Most notably, the critical four-way interaction between experiment, block, congruency, and PC was not significant. Thus, there was no evidence of an asymmetric list shifting effect independent of practice benefits. Indeed, experiment had no significant effects on errors and dropping the experiment factor from the LME again resulted in better fit (AIC = 1,001; BIC = 1,032) than the model with the experiment factor (AIC = 1,013; BIC = 1,070). As with the response times, there was no evidence that the two experiments differed in any meaningful way.

Discussion

The results of this reanalysis show the important role that practice plays in producing asymmetric list shifting. After accounting for the practice effects observed in Experiment 1b, the asymmetry in the list shifting effect was no longer significant in response times or errors. It is noteworthy, however, that the asymmetric list shifting effect does *numerically* exceed the practice effects observed in Experiment 1b by a noticeable amount. This might suggest that there is more to the asymmetry than just practice (e.g., conflict adaptation). At minimum, however, the present analysis demonstrates a major role for practice in the asymmetry.

Analysis 2: Experiment 1 Simulation

Analysis 1 demonstrated the important role of practice in the asymmetric list shifting effect. Analysis 2 aims to determine whether a learning model is able to simulate the results of Abrahamse et al. (2013) without a conflict adaptation mechanism. To this end, the Parallel Episodic Processing (PEP) model was used (Schmidt, 2013c), represented visually in Figure 3. In the model, word and color Input nodes are first activated, then compete in the Identity nodes (producing congruency effects), before passing on activation to Response nodes. On each trial, the PEP makes a new Episode node, linking the word Input nodes to Episode nodes, and Episode nodes to Response nodes. Subsequent episodic retrieval produces contingency learning, because a given word will retrieve primarily trials in which the high contingency response was made. Note that colors are not connected to Episode nodes in the PEP merely for computational simplicity. These connections are not relevant for contingency learning, because color-response correspondences are always 100% consistent. The model also learns to time responses rhythmically (Schmidt, 2013b; Schmidt & Weissman, 2015), but this mechanism is not relevant for the current simulation.[1]

Method

Model changes. One key change to the model was made to investigate practice effects. Full details are presented in the Appendix, but a briefer conceptual explanation is given here. In order to simulate practice effects, it was assumed that each time a participant makes a given response, the ease of making that response to the stimulus is increased. More specifically, the connection between the relevant Identity and Response nodes is strengthened. This produces a general speed up over the course of the experiment, and an (incidental) decrease in the congruency effect. It is important to note that after these parameter changes, unreported simulations confirm that the model still produces item-specific PC, list-level PC, and Gratton effects. Thus, the current Version 1.4.0 of the PEP model is still able to simulate the findings that it was previously reported to simulate (see Schmidt, 2013b, 2013c; Schmidt & Weissman, 2015). Full Java source code for this and all previous versions of the PEP model can be found on the author's website (http://users.ugent.be/~jaschmid/PEP).

Table 2
Analysis 1 Response Time Linear Mixed Effects Results

Factor	Statistic
Intercept	$F(1, 38) = 871.790, p < .001$
Experiment	$F(1, 38) = .028, p = .868$
Block	$F(1, 114) = 90.678, p < .001$
Congruency	$F(1, 114) = 101.685, p < .001$
PC	$F(1, 43) = 2.709, p = .107$
Experiment × Block	$F(1, 114) = 2.209, p = .140$
Experiment × Congruency	$F(1, 114) = .251, p = .618$
Experiment × PC	$F(1, 43) < .001, p = .997$
Block × Congruency	$F(1, 114) = 3.535, p = .063$
Block × PC	$F(1, 42) = 8.896, p = .005$
Congruency × PC	$F(1, 114) = 25.290, p < .001$
Experiment × Block × Congruency	$F(1, 114) = .820, p = .367$
Experiment × Block × PC	$F(1, 42) = 4.303, p = .044$
Experiment × Congruency × PC	$F(1, 114) = 1.180, p = .280$
Block × Congruency × PC	$F(1, 114) = 2.699, p = .103$
Experiment × Block × Congruency × PC	$F(1, 114) = 2.745, p = .100$

Note. PC = proportion congruent.

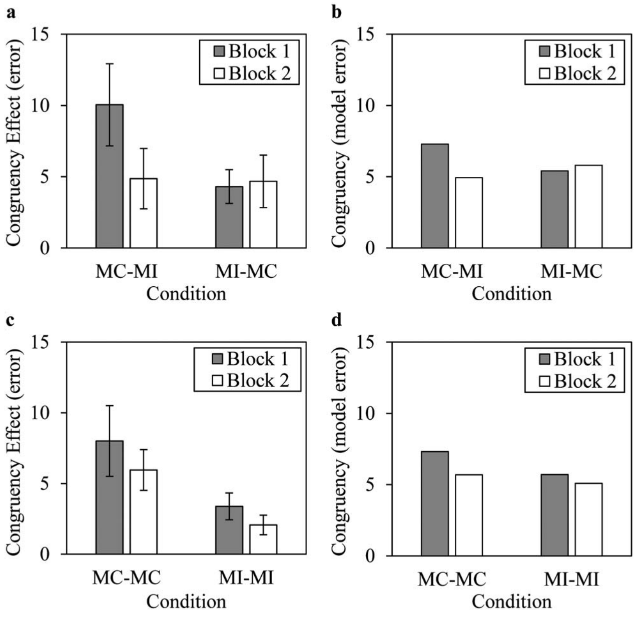

Figure 2. Experiment 1a (a) percentage errors and (b) model errors, and Experiment 1b (c) percentage errors and (d) model errors for Abrahamse et al. (2013). MC = mostly congruent; MI = mostly incongruent.

Procedure. The model was presented with the exact same manipulations as those in Experiments 1a and 1b of Abrahamse et al. (2013; see Table 1). In mostly congruent blocks, each of four words was presented 54 times in its congruent color and six times in each of the remaining three colors (288 trials). In mostly incongruent blocks, each word was presented equally often (18 times) in all four colors (288 trials). For Experiment 1a, half of the "participants" received a mostly congruent block followed by a mostly incongruent block, and half the reverse. For Experiment 1b, half received two mostly congruent blocks, and the other half two mostly incongruent blocks. There were 250 simulated participants for each of the four conditions (MC-MI, MI-MC, MC-MC, MI-MI), for a total of 1,000.

Results

Given the very large number of simulated participants, reliability was very high. Statistics are not reported below, but every interpreted numerical difference was well below the conventional level of statistical significance (i.e., $\alpha = .05$). Both condition correct cycle times (simulated RT) and percentage errors are discussed. The data are presented in Table 4.

Cycle times. The simulated response time congruency effects for Experiments 1a and 1b are presented in Figures 1b and 1d, respectively. Most importantly, the simulation produces asymmetric

---

[1] Temporal learning might conceivably contribute to some of the patterns in the data, but it does not produce an asymmetric list shifting effect, at least as currently programmed. This was confirmed in the older version of the model without the newly added practice mechanism.

Table 3
Analysis 1 Percentage Error Linear Mixed Effects Results

Factor	Statistic
Intercept	$F(1, 38) = 94.818, p < .001$
Experiment	$F(1, 38) = .266, p = .609$
Block	$F(1, 114) = .067, p = .796$
Congruency	$F(1, 114) = 81.338, p < .001$
PC	$F(1, 59) = 3.749, p = .058$
Experiment × Block	$F(1, 114) = .002, p = .961$
Experiment × Congruency	$F(1, 114) = .871, p = .353$
Experiment × PC	$F(1, 59) = .137, p = .713$
Block × Congruency	$F(1, 114) = 2.895, p = .092$
Block × PC	$F(1, 55) = .038, p = .846$
Congruency × PC	$F(1, 114) = 8.584, p = .004$
Experiment × Block × Congruency	$F(1, 114) = .093, p = .761$
Experiment × Block × PC	$F(1, 55) = .022, p = .883$
Experiment × Congruency × PC	$F(1, 114) = .379, p = .540$
Block × Congruency × PC	$F(1, 114) = 1.921, p = .168$
Experiment × Block × Congruency × PC	$F(1, 114) = 1.172, p = .281$

Note. PC = proportion congruent.

list shifting: The decrease in the congruency effect from Block 1 to Block 2 in the MC-MI group (53 cycles) was 75 cycles larger than the (non)increase in the MI-MC condition (−22 cycles). This shows that the competing forces of practice and contingency effects produce an asymmetrical list shifting effect. For Experiment 1b, the model produced a decrease in the congruency effect with block. Specifically, there was a 53 cycle decrease in the MC-MC condition, and a 41 cycle decrease in the MI-MI condition. This demonstrates that the practice mechanism works as intended.

Simulated errors. The simulated error percentage data produced a similar pattern of data as the cycle times and are presented in Figures 2b and 2d. Most importantly, the simulation produces asymmetric list shifting: The decrease in the congruency effect from Block 1 to Block 2 in the MC-MI group (2.4%) was 2.0% larger than the increase in the MI-MC condition (0.4%). The simulated control experiment also produced decreases in the congruency effect, though this was more evident in the MC-MC condition (1.6%) than in the MI-MI condition (0.6%).

Discussion

Analysis 2 demonstrated the simple point that a contingency learning mechanism is entirely consistent with asymmetric list shifting effects, as long as it is assumed that performance improves with practice. The parameters of the model were not strategically adjusted such that the data perfectly matched the participant data. More generally, the parameters of the PEP model are not changed on an experiment-by-experiment basis to avoid overfitting the model to the data. This does mean, however, that the same parameterization is used for a wide range of tasks (e.g., verbal Stroop, manual Stroop, and prime-probe) with various design differences (e.g., set sizes, trial durations, etc.), so it is inevitable that some discrepancies between modeled and participant data will emerge. One is noteworthy in the present simulation. Congruency effects actually *decreased* in the MI-MC list, whereas there was a (nonsignificant) increase in the participant data. This is due to the relatively small PC effect in the simulated data (16 cycles). As the author confirmed in supplementary simulations,[2] this probably indicates that the contingency mechanism could have been stronger, thereby increasing the overall PC effect (i.e., because it is the contingency mechanism that is primarily responsible for the PC effect in the PEP model). However, the key point, demonstrated here computationally, is that contingency and practice effects work in opposition to each other in the MI-MC list, whereas they work in concert in the MC-MI list. This produces asymmetric list shifting. Additional assumptions about conflict adaptation may be unnecessary.

Analysis 3: Experiment 2 Simulation

Abrahamse et al. (2013) also conducted a second experiment using different stimulus frequencies. This experiment did not have a corresponding control experiment (i.e., similar to Experiment 1b), so an analysis akin to Analysis 1 was not possible. However, the differences between Experiments 1 and 2 are interesting in several respects, so it is worth considering whether the PEP model can simulate the results of this experiment as well. The design of Experiment 2 is presented in Table 5. One notable feature of this experiment is that it makes use of *inducer items*, which are manipulated for PC (e.g., "red" and "green" in Table 5) and intermixed *transfer items*, which are not manipulated for PC (e.g., "yellow" and "blue" in Table 5). Only the inducer items produced asymmetric list shifting effects. Both inducer and transfer items are nevertheless simulated for reader reference.

Also unique to Experiment 2, there were two list shifts in the experiment (i.e., MC-MI-MC or MI-MC-MI). There were three (significantly or marginally) reliable changes, all within the MC-MI-MC group. First, there was a significant drop in the congruency effect from Block 1 to Block 2, which was larger than the nonsignificant increase in the MI-MC-MI group. Second, there was a marginal increase from Block 2 to Block 3. Third, there was a significant drop in the congruency effect from Block 1 to Block 3.

Method

Model changes. No changes to the model presented in Analysis 2 were made.

Procedure. The model was presented with the exact same manipulations as those in Experiment 2 of Abrahamse et al. (2013; see Table 5). In mostly congruent blocks, one pair of words (e.g., red and green) were presented 16 times in the congruent color and four times in the other incongruent color (inducer items). Another pair of words (e.g., blue and yellow) were presented 10 times each in the congruent and incongruent colors (transfer items; 80 trials total). Mostly incongruent blocks were identical, except that the contingencies for inducer items were reversed. For the MC-MI-MC group, the model was presented with five mostly congruent blocks, followed by two mostly incongruent blocks, followed

---

[2] The contingency mechanism can be strengthened relative to the practice mechanism by increasing the maximum retrieval from episodic memory (.25) to boost contingency learning, increasing the response deadline (.55) to compensate for the contingency boost, and increasing the starting connection strength between identity and response nodes (.85) to weaken practice benefits. This also increases overall RT (like the participant data), so the model was given more cycles (4,000) for finding a response (like the actual experiment). This increases the overall PC effect (58 cycles), eliminates the decrease in the MI-MC condition (one cycle increase), and even increases the asymmetry (115 cycles).

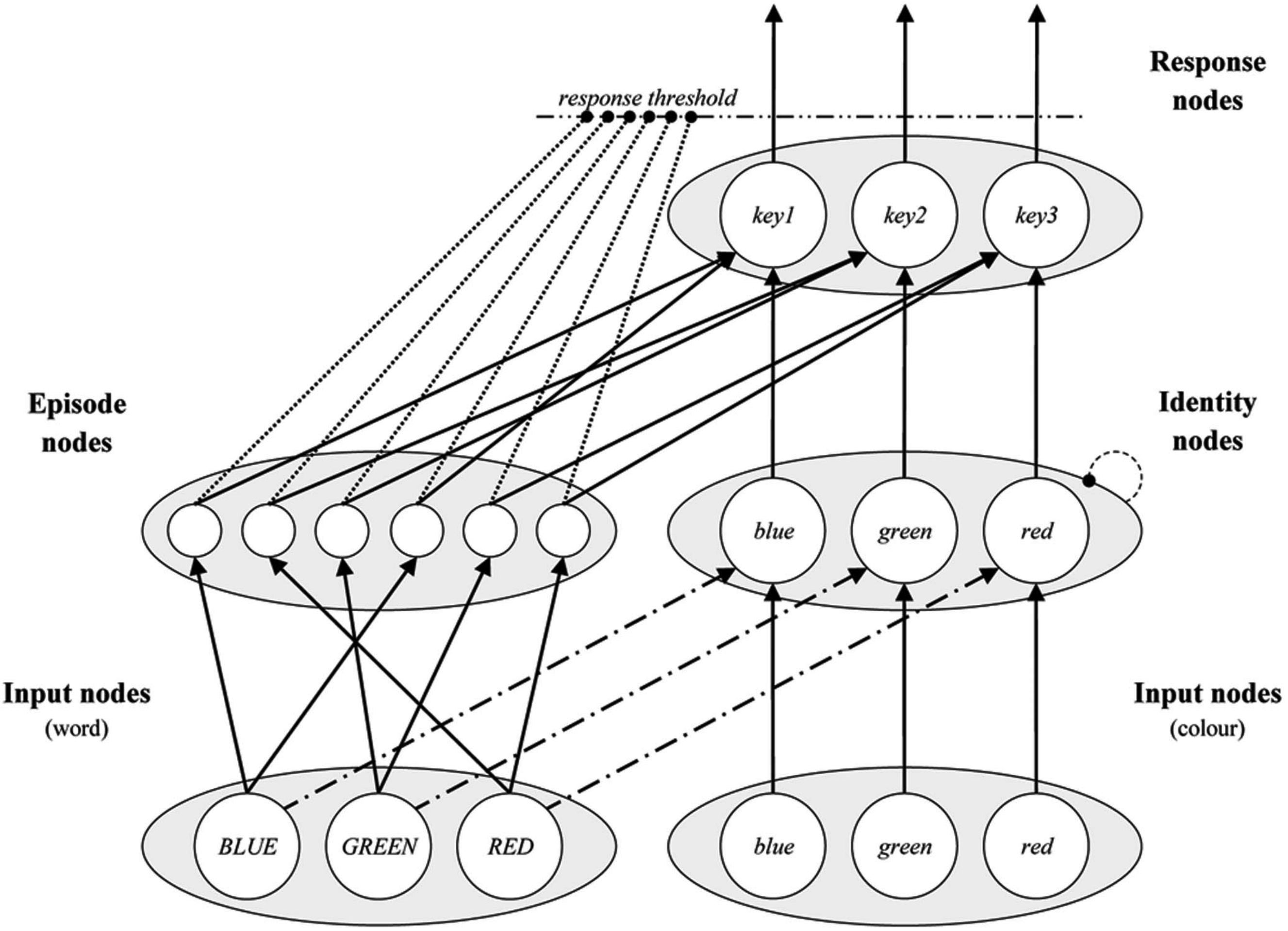

Figure 3. Visual representation of the Parallel Episodic Processing model. Connections between identity and response nodes are strengthened with practice.

by two more mostly congruent blocks. For the MI-MC-MI group, the reverse contingencies were used. For both conditions, 250 simulated participants were run, for a total of 500.

Results

As in Analysis 2, reliability was again very high, so statistics are not reported. The data are presented in Table 6.

Table 4
Analysis 2 Simulation Data

	Block 1				Block 2			
	Cycles		Errors		Cycles		Errors	
Experiment	C	I	C	I	C	I	C	I
Experiment 1a								
MC-MI	364	549	1.4	8.6	353	477	1.4	6.5
MI-MC	373	534	1.2	6.7	344	483	1.9	5.5
Experiment 1b								
MC-MC	365	555	1.4	9.1	343	483	1.9	7.7
MI-MI	375	535	1.2	6.5	354	477	1.5	6.3

Note. C = congruent; I = incongruent; MC = mostly congruent; MI = mostly incongruent.

Cycle times. The simulated response times for Experiment 2 inducer items are presented in Figure 4b. Most importantly, the simulation produces asymmetric list shifting: The decrease in the congruency effect from Block 1 to Block 2 in the MC-MI-MC group (73 cycles) was 52 cycles larger than the increase in the MI-MC-MI condition (21 cycles). Additionally, in the MC-MI-MC group there was a 28 cycle increase from Block 2 to Block 3 and a 45-cycle decrease from Block 1 to Block 3. This matches the pattern of data observed in the original report. Note that the original report found no reliable differences between blocks in the MI-MC-MI group. Of course, the model has much more power to detect small differences,

Table 5
Experiment 2 Stimulus Pairings (Abrahamse et al., 2013)

	Mostly congruent				Mostly incongruent			
Colors	Red	Green	Yellow	Blue	Red	Green	Yellow	Blue
Red	16	4			4	16		
Green	4	16			16	4		
Yellow			10	10			10	10
Blue			10	10			10	10

Table 6
Analysis 3 Simulation Data

	Block 1				Block 2				Block 3			
	Cycles		Errors		Cycles		Errors		Cycles		Errors	
Condition	C	I	C	I	C	I	C	I	C	I	C	I
MC-MI-MC												
Inducer	361	541	1.5	8.2	351	455	1.6	6.4	344	482	1.8	6.9
Transfer	356	500	1.4	7.9	351	467	1.7	6.8	345	464	2.1	7.6
MI-MC-MI												
Inducer	368	479	1.3	6.3	349	475	1.6	6.7	352	452	1.1	6.6
Transfer	369	509	1.3	6.2	351	465	1.7	6.8	352	465	1.5	6.7

Note. C = congruent; I = incongruent; MC = mostly congruent; MI = mostly incongruent.

but note that the numerical differences between blocks are smaller in the MI-MC-MI group. Similarly, transfer items produced no significant list shifting effects in the original report, but the simulated results are nevertheless presented in Figure 4d for reference.

Simulated errors. In the original report, the error data provided no significant list shifting effects. Of course, the modeled data has much more statistical power. Notably, the simulated error percentages for inducer items produced a similar pattern of data as the cycle times and are presented in Figure 5b. Most importantly, the decrease in the congruency effect from Block 1 to Block 2 in the MC-MI-MC group (2.5%) was 2.5% larger than the (non)increase in the MI-MC-MI condition (<0.0%).

Discussion

Analysis 3 demonstrated that the same computational model used to simulate Experiments 1a and 1b of Abrahamse et al. (2013) can also simulate the results of their Experiment 2. Most critically, bigger list shifting effects are observed between blocks in the MC-MI-MC group than in the MI-MC-MI group. Together with Analyses 1 and 2, this demonstrates the feasibility of a contingency learning account of asymmetric list shifting.

General Discussion

In the debate between the conflict adaptation and simple learning perspectives of the PC effect, the asymmetric list shifting effect seems particularly interesting. While most reports of purported evidence for conflict adaptation in the PC effect can be easily and powerfully explained by simple contingency and temporal learning processes, the asymmetric list shifting effect seemingly provides unilateral support for conflict adaptation. However, this paper presented the case that the asymmetric list shifting effects observed by Abrahamse et al. (2013) might be explainable, in whole or in part, by contingency learning, as long as it is additionally assumed that the congruency effect shrinks with practice. Analysis 1 illustrated the important role of practice

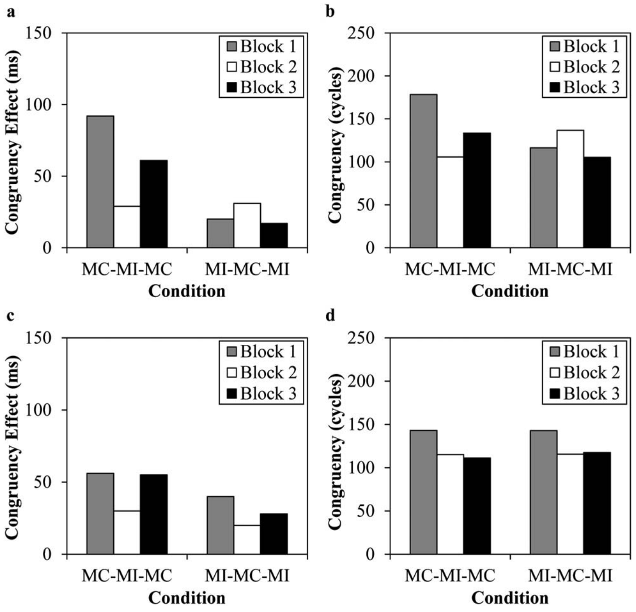

Figure 4. Experiment 2 inducer item (a) response times and (b) model cycle times, and transfer item (c) response times and (d) model cycle times for Abrahamse et al. (2013). MC = mostly congruent; MI = mostly incongruent.

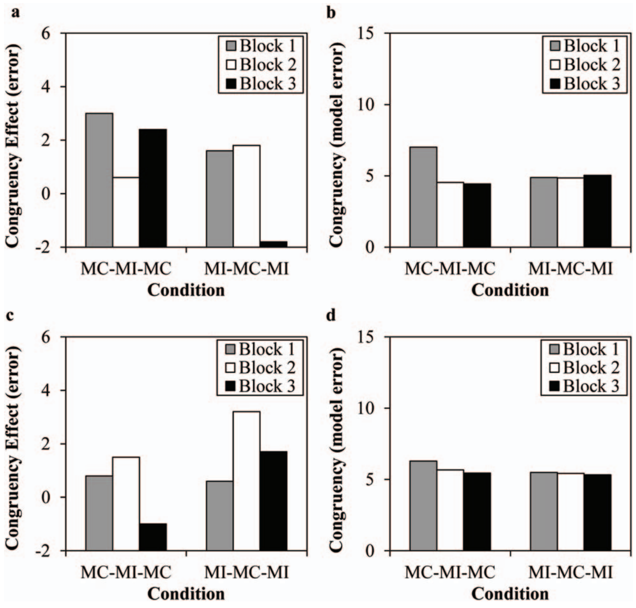

Figure 5. Experiment 2 inducer item (a) percentage errors and (b) model errors, and transfer item (c) percentage errors and (d) model errors for Abrahamse et al. (2013). MC = mostly congruent; MI = mostly incongruent.

effects, by showing that the asymmetry is not robust to controls for practice. Analyses 2 and 3 with the PEP model further demonstrated the plausibility of a contingency learning account by showing that learning and practice mechanisms produce the asymmetries observed in participant data.

Whether contingency learning and practice explain the entire asymmetric list shifting effect, however, is uncertain. There were still hints in the data of a residual asymmetric list shifting effect. If this is more than just noise, then conflict adaptation might play some role in the effect. That said, the current results demonstrate that a contingency learning account can provide a potentially sufficient explanation for asymmetric list shifting. This is important, because the asymmetry might otherwise seem to undermine the strong case that consideration of the impact of simple learning and memory processes on the PC effect eliminates the need to make assumptions about conflict monitoring or adaptation.

Practice Effects

Another aim of the current paper is to highlight the importance of practice effects. Congruency effects change in magnitude over time via practice (Dulaney & Rogers, 1994; Ellis & Dulaney, 1991; MacLeod, 1998; Simon et al., 1973; Stroop, 1935), and failing to take this fact into consideration when comparing congruency effects across two temporally separated blocks can lead to potentially incorrect conclusions about cognitive control. Another example of this comes from work with the Gratton effect (i.e., smaller congruency effects following an incongruent trial). Sheth et al. (2012) found that the Gratton effect was abolished after lesioning the dorsal anterior cingulate cortex and concluded that the dorsal anterior cingulate cortex plays a causal role in behavioral adaptation. However, van Steenbergen, Haasnoot, Bocanegra, Berretty, and Hommel (2015) subsequently demonstrated that replacing the lesion with a filler task *also* eliminated the Gratton effect. That is, the Gratton effect was reduced, but simply due to practice.

Attention Capture and Stimulus Informativeness

If an asymmetric list shifting effect *does* exist independent of practice, one further design feature of Experiment 1 of Abrahamse et al. (2013) is worth considering. Items in the mostly congruent and mostly incongruent blocks differ in stimulus informativeness. That is, words in the mostly congruent condition are strongly predictive of the correct (i.e., congruent) response. In contrast, words in the mostly incongruent condition are unpredictive (i.e., they are presented equally often in all colors). It is well known that predictive stimuli attract attention (Chun & Jiang, 1998; Cosman & Vecera, 2014; Hutcheon & Spieler, 2014; Melara & Algom, 2003). As Schmidt (2014a) points out, this means that mostly congruent stimuli will attract more attention than mostly incongruent stimuli if the former are more informative than the latter. This *attention capture* view shares some similarities with the conflict adaptation view, except that it is proposed that attention is drawn toward informative stimuli, rather than away from conflicting stimuli. Distinguishing between these two possibilities can be achieved by making mostly incongruent words just as predictive of an incongruent response as mostly congruent words are of a congruent response (e.g., see Table 4).[3]

Concluding Remarks

It is hoped that the current paper strengthens the point of Schmidt (2013a) that the currently published data on PC effects are too ambiguous to definitively conclude whether or not conflict adaptation plays a role in addition to basic learning and memory confounds. Although far from a consensus, some data suggests that simple learning processes may be sufficient to explain “item-specific” (Atalay & Misirlisoy, 2012; Grandjean et al., 2013; Hazeltine & Mordkoff, 2014; Schmidt, 2013c; Schmidt & Besner, 2008), “list-level” (Schmidt, 2013b, 2014b), and “context-specific” PC effects (Schmidt et al., 2014). The current results suggest that conflict-unrelated learning is also sufficient to explain asymmetric list shifting. The elegance of this view is that the mechanisms proposed are uncontroversial and necessary for explaining a broad range of learning and memory phenomena. It is hoped that this report will prompt further research on practice in order to determine whether and in which scenarios genuine conflict adaptation can be observed.

---

[3] Of course, this does assume that it is equally easy to learn a congruent contingency (e.g., that the word “red” predicts the red response) as it is to learn an incongruent contingency (e.g., that the word “red” predicts a green response). This may or may not be true.

References

Abrahamse, E. L., Duthoo, W., Notebaert, W., & Risko, E. F. (2013). Cognitive control in a dynamic environment: The asymmetrical list shifting effect. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 39,* 1552–1562. http://dx.doi.org/10.1037/a0032426

Atalay, N. B., & Misirlisoy, M. (2012). Can contingency learning alone account for item-specific control? Evidence from within- and between-language ISPC effects. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 38,* 1578–1590. http://dx.doi.org/10.1037/a0028458

Blais, C., & Bunge, S. (2010). Behavioral and neural evidence for item-specific performance monitoring. *Journal of Cognitive Neuroscience, 22,* 2758–2767. http://dx.doi.org/10.1162/jocn.2009.21365

Botvinick, M. M., Braver, T. S., Barch, D. M., Carter, C. S., & Cohen, J. D. (2001). Conflict monitoring and cognitive control. *Psychological Review, 108,* 624–652. http://dx.doi.org/10.1037/0033-295X.108.3.624

Bugg, J. M., & Hutchison, K. A. (2013). Converging evidence for control of color-word Stroop interference at the item level. *Journal of Experimental Psychology: Human Perception and Performance, 39,* 433–449. http://dx.doi.org/10.1037/a0029145

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,* 844–859. http://dx.doi.org/10.1037/a0019957

Cheesman, J., & Merikle, P. M. (1986). Distinguishing conscious from unconscious perceptual processes. *Canadian Journal of Psychology, 40,* 343–367. http://dx.doi.org/10.1037/h0080103

Chun, M. M., & Jiang, Y. (1998). Contextual cueing: Implicit learning and memory of visual context guides spatial attention. *Cognitive Psychology, 36,* 28–71. http://dx.doi.org/10.1006/cogp.1998.0681

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,* 332–361. http://dx.doi.org/10.1037/0033-295X.97.3.332

Cosman, J. D., & Vecera, S. P. (2014). Establishment of an attentional set via statistical learning. *Journal of Experimental Psychology: Human Perception and Performance, 40,* 1–6. http://dx.doi.org/10.1037/a0034489

Crump, M. J. C., & Milliken, B. (2009). The flexibility of context-specific control: Evidence for context-driven generalization of item-specific control settings. *Quarterly Journal of Experimental Psychology: Human Experimental Psychology, 62,* 1523–1532. http://dx.doi.org/10.1080/17470210902752096

Dulaney, C. L., & Rogers, W. A. (1994). Mechanisms underlying reduction in Stroop interference with practice for young and old adults. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 20,* 470–484. http://dx.doi.org/10.1037/0278-7393.20.2.470

Ellis, N. R., & Dulaney, C. L. (1991). Further evidence for cognitive inertia of persons with mental retardation. *American Journal on Mental Retardation, 95,* 613–621.

Grandjean, J., D'Ostilio, K., Fias, W., Phillips, C., Balteau, E., Degueldre, C., . . . Collette, F. (2013). Exploration of the mechanisms underlying the ISPC effect: Evidence from behavioral and neuroimaging data. *Neuropsychologia, 51,* 1040–1049. http://dx.doi.org/10.1016/j.neuropsychologia.2013.02.015

Hazeltine, E., & Mordkoff, J. T. (2014). Resolved but not forgotten: Stroop conflict dredges up the past. *Frontiers in Psychology, 5,* 1327. http://dx.doi.org/10.3389/fpsyg.2014.01327

Heathcote, A., Brown, S., & Mewhort, D. J. K. (2000). The power law repealed: The case for an exponential law of practice. *Psychonomic Bulletin & Review, 7,* 185–207. http://dx.doi.org/10.3758/BF03212979

Hutcheon, T. G., & Spieler, D. H. (2014). Contextual influences on the sequential congruency effect. *Psychonomic Bulletin & Review, 21,* 155–162. http://dx.doi.org/10.3758/s13423-013-0473-5

Hutchison, K. A. (2011). The interactive effects of listwide control, item-based control, and working memory capacity on Stroop performance. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 37,* 851–860. http://dx.doi.org/10.1037/a0023437

Jacoby, L. L., Lindsay, D. S., & Hessels, S. (2003). Item-specific control of automatic processes: Stroop process dissociations. *Psychonomic Bulletin & Review, 10,* 638–644. http://dx.doi.org/10.3758/BF03196526

Lindsay, D. S., & Jacoby, L. L. (1994). Stroop process dissociations: The relationship between facilitation and interference. *Journal of Experimental Psychology: Human Perception and Performance, 20,* 219–234. http://dx.doi.org/10.1037/0096-1523.20.2.219

Logan, G. D. (1988). Toward an instance theory of automatization. *Psychological Review, 95,* 492–527. http://dx.doi.org/10.1037/0033-295X.95.4.492

Lowe, D. G., & Mitterer, J. O. (1982). Selective and divided Attention in a Stroop task. *Canadian Journal of Psychology, 36,* 684–700. http://dx.doi.org/10.1037/h0080661

MacLeod, C. M. (1998). Training on integrated versus separated Stroop tasks: The progression of interference and facilitation. *Memory & Cognition, 26,* 201–211. http://dx.doi.org/10.3758/BF03201133

Melara, R. D., & Algom, D. (2003). Driven by information: A tectonic theory of Stroop effects. *Psychological Review, 110,* 422–471. http://dx.doi.org/10.1037/0033-295X.110.3.422

Myung, I. J., Kim, C., & Pitt, M. A. (2000). Toward an explanation of the power law artifact: Insights from response surface analysis. *Memory & Cognition, 28,* 832–840. http://dx.doi.org/10.3758/BF03198418

Newell, A., & Rosenbloom, P. S. (1981). Mechanisms of skill acquisition and the law of practice. In J. R. Anderson (Ed.), *Cognitive skills and their acquisition* (pp. 1–55). Hillsdale, NJ: Erlbaum.

Schmidt, J. R. (2013a). Questioning conflict adaptation: Proportion congruent and Gratton effects reconsidered. *Psychonomic Bulletin & Review, 20,* 615–630. http://dx.doi.org/10.3758/s13423-012-0373-0

Schmidt, J. R. (2013b). Temporal learning and list-level proportion congruency: Conflict adaptation or learning *when* to respond? *PLoS ONE, 8,* e82320. http://dx.doi.org/10.1371/journal.pone.0082320

Schmidt, J. R. (2013c). The parallel episodic processing (PEP) model: Dissociating contingency and conflict adaptation in the item-specific proportion congruent paradigm. *Acta Psychologica, 142,* 119–126. http://dx.doi.org/10.1016/j.actpsy.2012.11.004

Schmidt, J. R. (2014a). Contingencies and attentional capture: The importance of matching stimulus informativeness in the item-specific proportion congruent task. *Frontiers in Psychology, 5,* 540. http://dx.doi.org/10.3389/fpsyg.2014.00540

Schmidt, J. R. (2014b). List-level transfer effects in temporal learning: Further complications for the list-level proportion congruent effect. *Journal of Cognitive Psychology, 26,* 373–385. http://dx.doi.org/10.1080/20445911.2014.896367

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,* 514–523. http://dx.doi.org/10.1037/0278-7393.34.3.514

Schmidt, J. R., Crump, M. J. C., Cheesman, J., & Besner, D. (2007). Contingency learning without awareness: Evidence for implicit control. *Consciousness and Cognition, 16,* 421–435. http://dx.doi.org/10.1016/j.concog.2006.06.010

Schmidt, J. R., Lemercier, C., & De Houwer, J. (2014). Context-specific temporal learning with non-conflict stimuli: Proof-of-principle for a learning account of context-specific proportion congruent effects. *Frontiers in Psychology, 5,* 1241. http://dx.doi.org/10.3389/fpsyg.2014.01241

Schmidt, J. R., & Weissman, D. H. (2015). Congruency sequence effects and previous response times: Conflict adaptation or temporal learning? *Psychological Research*. Advance online publication. http://dx.doi.org/10.1007/s00426-015-0681-x

Shedden, J. M., Milliken, B., Watter, S., & Monteiro, S. (2013). Event-related potentials as brain correlates of item specific proportion congruent effects. *Consciousness and Cognition, 22,* 1442–1455. http://dx.doi.org/10.1016/j.concog.2013.10.002

Sheth, S. A., Mian, M. K., Patel, S. R., Asaad, W. F., Williams, Z. M., Dougherty, D. D., . . . Eskandar, E. N. (2012). Human dorsal anterior cingulate cortex neurons mediate ongoing behavioural adaptation. *Nature, 488,* 218–221. http://dx.doi.org/10.1038/nature11239

Simon, J. R., Craft, J. L., & Webster, J. B. (1973). Reactions toward the stimulus source: Analysis of correct responses and errors over a five-day period. *Journal of Experimental Psychology, 101,* 175–178. http://dx.doi.org/10.1037/h0035766

Stroop, J. R. (1935). Studies on interference in serial verbal reactions. *Journal of Experimental Psychology, 18,* 643–662. http://dx.doi.org/10.1037/h0054651

van Steenbergen, H., Haasnoot, E., Bocanegra, B. R., Berretty, E. W., & Hommel, B. (2015). Practice explains abolished behavioural adaptation after human dorsal anterior cingulate cortex lesions. *Scientific Reports, 5,* 9721. http://dx.doi.org/10.1038/srep09721

Wühr, P., Duthoo, W., & Notebaert, W. (2015). Generalizing attentional control across dimensions and tasks: Evidence from transfer of proportion-congruent effects. *Quarterly Journal of Experimental Psychology: Human Experimental Psychology, 68,* 779–801. http://dx.doi.org/10.1080/17470218.2014.966729

Appendix

Model Changes

One new change was added to the model that is relevant to asymmetric list shifting. In order to capture both the general decrease in overall response times and the decrease in congruency effects over the course of the experiment, the connections between identity nodes and response nodes were adjusted over time. Specifically, the connection strength between a given identity and response node i was updated on every cycle wherein activation of the identity node exceeded the activation threshold with Formula (A1),

$$strength_i = strength_i(1 - decay) + .0001 \tag{A1}$$

The *decay* parameter was set at .0001. On the first trial, *strength* was .6. The *strength* value thus increases in a decelerating function. That is, larger increases in strength occur in the earliest trials, then changes become progressively smaller with later trials.

The *strength* value is then used in Formula (A2) to determine how much activation is passed from an identity node to a response node,

$$output_i = (activation_i - threshold)(noise)(strength_i) \tag{A2}$$

Aside from the *strength* modifier, Formula (A2) is identical in previous versions of the model. Note that Formula (A2) is only calculated when the *activation* of a node i exceeds the *threshold*, and *noise* is a random number between 0 and 5 on each trial. The net result of these formulas is an overall speedup in responding with decreasing congruency effects (i.e., less time for interference), especially early on in the experiment, consistent with the power function.

The only other minor change to the model is that the maximum retrieval rate from episode nodes was set to .1. Earlier versions of the model had a stronger retrieval rate (.2), which seemed too strong. A recent adaptation lowered this rate to (.01), but this was an overcompensation.

Received September 8, 2015
Revision received January 6, 2016
Accepted January 7, 2016 ■