Proceedings of the Annual Meeting of the Cognitive Science Society

Title

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Journal

Proceedings of the Annual Meeting of the Cognitive Science Society, 42(0)

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Publication Date

2020

Peer reviewed

Dissociating adaptation to word-specific and color-specific conflict frequency in the Stroop task

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Abstract

In the Stroop task, congruency effects are typically larger for color words presented mainly in their congruent color than for color words presented mainly in incongruent colors. However, the nature of this item-specific proportion congruent (ISPC) effect is debated: It might be produced by either conflict-adaptation processes (e.g., focus attention to task-relevant information when the word BLUE appears) and/or a more general contingency-learning process (e.g., anticipate a green response when the word BLUE appears). We re-examined the role of conflict-adaptation processes in this paradigm in two experiments. In both experiments, a conflict-adaptation effect emerged on stimuli matched on contingency. Further, in Experiment 2, we found separate effects of adaptation to the frequency of conflict specific to the color and word dimensions of individual stimuli. These results challenge the contingency-learning account of the ISPC effect and suggest that conflict-adaptation processes in this paradigm may depend on both task-relevant and task-irrelevant information.

Keywords: item-specific proportion-congruent effect; conflict adaptation; Stroop; contingency learning

Introduction

An ongoing debate in cognitive control research concerns whether the human control system adapts to situations where resolution of conflict is frequently versus infrequently required (Bugg & Crump, 2012; Schmidt, 2013b, 2019). One such situation was examined by Jacoby, Lindsay and Hessels (2003), who reported that in the Stroop (1935) task, congruency effects (i.e., the color-naming latency difference between incongruent stimuli, e.g., the word BLUE written in green, and congruent stimuli, e.g., the word RED written in red) are larger for Mostly Congruent (MC) items (e.g., the word RED presented most often in red) than for Mostly Incongruent (MI) items (e.g., the word BLUE presented most often in green). While further research established the robustness of this item-specific proportion (ISPC) congruent effect (e.g., Bugg, Jacoby, & Toth, 2008), its cause is currently unclear.

According to the control account, the ISPC effect would reflect the use of a process of adaptation to the frequency of conflict specific to individual word (or color) stimuli, with early processing of specific stimuli regulating recruitment of appropriate control processes (e.g., focus attention to task-relevant information when the MI word BLUE appears, but not when the MC word RED appears), at least in some situations (Bugg & Hutchison, 2013; Bugg, Jacoby, & Chanani, 2011; Spinelli, Krishna, Perry, & Lupker, in review; Spinelli & Lupker, 2020a). Alternatively (or additionally), the ISPC effect might reflect the more general process of learning contingencies between a word and the typical response made to that word (Schmidt & Besner, 2008). For instance, if the (MI) word BLUE appears most often in green, individuals may learn to associate the word BLUE with the green response, an associative learning process that is also found when noncolor words are used (Lin & MacLeod, 2018; Schmidt, Crump, Cheesman, & Besner, 2007). According to the contingency-learning account, this process would explain the ISPC effect entirely, with adaptation to conflict frequency playing no role at all.

In recent years, a few researchers tried to directly dissociate the control account and the contingency-learning account of the ISPC effect. One of the most straightforward dissociation procedures was that used by Schmidt (2013a). Schmidt constructed a Stroop task in which MC words, e.g., RED, and MI words, e.g., BLUE, could be compared on what were “contingency matched” incongruent trials. For example, RED and BLUE were presented in yellow with the same (low) probability. The existence of a process of adaptation to item-specific conflict frequency would imply that because MI words should induce focused attention to task-relevant information whereas MC words should induce relaxed attention, MC words should be harder to respond to than MI words when presented in those contingency-matched incongruent colors. However, performance on MC and MI words was equivalent when those words appeared in the critical incongruent colors, suggesting that no process of adaptation to item-specific conflict frequency was in use. In contrast, a robust contingency-learning effect emerged in the comparison between high-probability and low-probability color-word combinations on “conflict frequency matched” incongruent trials, e.g., color naming was faster to the MI word BLUE in the high-probability color green compared with BLUE in yellow, a low-probability color for that word. These results would appear to offer strong support to the idea that the ISPC effect in the Stroop task has “everything to do with contingency” and “nothing to with congruency” (Schmidt & Besner, 2008).

The primary purpose of the present research was to modify Schmidt’s (2013a) dissociation procedure in order to address a potential problem in his experiment. In his design, the critical comparison for probing adaptation to item-specific conflict frequency involved a contrast between MC words and MI words when presented in low-probability incongruent colors. However, compared to the traditional ISPC paradigm (Jacoby et al., 2003), this comparison was atypical as it was based on stimuli that combined words that frequently appeared in incongruent colors, i.e., MI words, and colors that frequently appeared with congruent words, i.e., MC colors. For example, BLUE was a word associated with frequent conflict (an MI word), however, in the crucial conditions, it appeared in yellow, a color that was associated with infrequent conflict (as this color appeared 70% of the time with the congruent word YELLOW). Since adaptation to color-specific conflict frequency in the Stroop task appears to be possible (Bugg & Hutchison, 2013), it is not clear whether and how the contrast between color-specific and word-specific information was resolved for those items in Schmidt's (2013a) experiment.

In Experiment 1 (previously published in Spinelli & Lupker, 2020a), this potential problem was removed by constructing a design which was similar to Schmidt's (2013a) with the exception that the stimuli were divided into two sets, an MC set and an MI set, which were not permitted to cross. As a result, on the relevant incongruent trials, MC words were presented solely in (other) MC colors and MI words were presented solely in (other) MI colors (see Table 1). With this modification, word-specific and color-specific information, as in the original paradigm (Jacoby et al., 2003), provided convergent signals for either a word reading process (with MC stimuli) or a word inhibition process (with MI stimuli), thus offering a more appropriate situation to test the existence of a process of adaptation to item-specific conflict frequency.

A secondary purpose of the present research was to further dissociate between processes of adaptation to word-specific vs. color-specific conflict frequency. Such a dissociation was not possible in Experiment 1 because, as noted, word-specific and color-specific conflict frequency information was consistent for all of the stimuli in that experiment. In Experiment 2, we introduced a new set of stimuli, the "transfer" set, to examine adaptation to word-specific vs. color-specific conflict frequency independently. The transfer set included two colors and two words which were not part of either the MC set or the MI set. Both the transfer colors and the transfer words appeared in congruent and incongruent stimuli equally often, thus favoring neither focused attention to task-relevant information nor relaxed attention overall. However, the transfer colors were paired with both (incongruent) MC words (i.e., words favoring word reading) and (incongruent) MI words (i.e., words favoring word inhibition), allowing an examination of adaptation to word-specific conflict frequency. Similarly, the transfer words were paired with both (incongruent) MC colors (i.e., colors favoring word reading) and (incongruent) MI colors (i.e., colors favoring word inhibition), allowing an examination of adaptation to color-specific conflict frequency (see Table 2). In both Experiment 1 and Experiment 2, the relevant incongruent trials were matched on contingency (i.e., they had equal probability), thus eliminating contingency learning as an explanation for potential differences among them.

Experiment 1

Method

Participants Seventy-two students at the University of Western Ontario (age 17–27 years) participated for course credit. All participants were native English speakers and had normal or corrected-to-normal vision.

Materials Six color names (RED, YELLOW, BLACK, BLUE, GREEN, WHITE) were used as word distractors and the corresponding colors were used as target colors. The frequency of word-color combinations in one of the counterbalancings of the experiment is represented in Table 1. The stimuli were divided into two sets, with RED, YELLOW, BLACK and the corresponding colors forming one set, and BLUE, GREEN, WHITE, and the corresponding colors forming the other set. One set served as the MC set and the other set served as the MI set for each participant. In the MC set, each word appeared in its congruent color 48 times and in each of the two incongruent colors 8 times (the item-specific proportion of congruent items was thus 75%). Similarly, in the MI set, each word appeared in one incongruent color 48 times and in both the other incongruent color and the congruent color 8 times (the item-specific proportion of congruent items was thus 13%).[1]

As in Schmidt's (2013a) experiment, there were two critical types of incongruent items which could be distinguished in this design: 1) low-probability incongruent items in the MC set (in light gray in Table 1, e.g., RED in yellow), and 2) low-probability incongruent items in the MI set (in dark gray in Table 1, e.g., BLUE in white). These incongruent items were matched on contingency (both had the same low probability for the corresponding words), with the only difference between them being item-specific conflict frequency.

Overall, there were 384 items (168 congruent and 216 incongruent). The assignment of each set to the MC or the MI condition was counterbalanced across participants. The specific incongruent color serving as the high-probability color for words in the MI set was also counterbalanced across participants.

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[1] Note that this type of design implies an overall higher number of incongruent than congruent items, unlike in the traditional design where congruent and incongruent items are overall equally probable. The same is true for Experiment 2. What is crucial, however, is that in this design, as in the traditional one, a different probability of congruent vs. incongruent items exists for MC vs. MI stimuli.

Procedure Each trial began with a fixation symbol (“+”) displayed for 250 ms in the center of the screen followed by a colored word displayed for 2000 ms or until the participant’s response, which was recorded with a microphone connected to the testing computer. Participants were instructed to name the color of the word as quickly and as accurately as possible while ignoring the word itself.

Stimuli were presented in uppercase Courier New font, pt. 14, against a medium grey background. No feedback was provided. The experiment was divided into two equal-sized blocks (192 trials per block) with a self-paced pause in the middle. The order of trials within each block was randomized. Initially, participants performed a practice session including 6 trials in which a string of Xs (“XXXX”) was presented in each of the six colors used in the experiment. The experiment was run using DMDX (Forster & Forster, 2003) software.

Table 1: Template for the Frequency of Color-Word Combinations in Experiment 1.

		Word					
		MC words			MI words		
Color		RED	YELLOW	BLACK	BLUE	GREEN	WHITE
MC	Red	48	8	8			
colors	Yellow	8	48	8			
	Black	8	8	48			
MI	Blue				8	8	48
colors	Green				48	8	8
	White				8	48	8

Results and Discussion

The waveforms of responses were manually inspected with CheckVocal (Protopapas, 2007) to determine the accuracy of the response and the correct placement of timing marks. Prior to the analyses, invalid trials due to technical failures and responses faster than 300 ms or slower than 2000 ms (accounting for .9% of the data) were discarded.

A paired-samples t-test contrasting low-probability incongruent items in the MC set and low-probability incongruent items in the MI set indicated that latencies were significantly longer for the former (813 ms) than for the latter (798 ms), $t(71) = 2.55$, $SE = 5.90$, $p = .013$, $\eta_p^2 = .084$. There were no significant differences in error rates (MC = 3.76%; MI = 3.32%), $t(71) = .73$, $SE = .006$, $p = .468$, $\eta_p^2 = .007$.[2]

These results are consistent with the idea that humans adapt attention to the frequency of conflict specific to individual stimuli, with MI stimuli favoring focused attention to task-relevant information (and thus, reduced interference on incongruent trials) and MC stimuli favoring relaxed attention (and thus, increased interference on incongruent trials). However, these results do not reveal what type of information humans use to adapt to conflict frequency. They could use word-specific information, color-specific information, or both. For instance, with MI stimuli, attention could be focused to task-relevant information upon recognition of the MI word (e.g., the word BLUE) and/or upon recognition of the MI color (e.g., the color blue). Experiment 2 was designed to further examine this issue by dissociating adaptation to word-specific and color-specific conflict frequency information in the ISPC paradigm.

Experiment 2

Method

Participants Seventy-two students at the University of Western Ontario (age 17–31 years) participated for course credit. All participants were native English speakers and had normal or corrected-to-normal vision.

Materials The words and the colors used were the same six words and colors as in Experiment 1, but arranged differently. The frequency of word-color combinations in one of the counterbalancings of the experiment is represented in Table 2. The stimuli were divided into three sets, with RED, BLUE and the corresponding colors forming one set, GREEN, WHITE and the corresponding colors forming another set, and YELLOW, BLACK and the corresponding colors forming the third set. For each participant, one set served as the MC set, another set served as the MI set, and the third set served as the transfer set. In the MC set, each word appeared 46 times in its congruent color, 2 times in the other (incongruent) color in that set, and 16 times in one of the (incongruent) transfer colors (the item-specific proportion of congruent items was thus 72%). Similarly, in the MI set, each word appeared 2 times in its congruent color, 46 times in the other (incongruent) color in that set, and 16 times in one of the (incongruent) transfer colors (the item-specific proportion of congruent items was thus 3%). In the transfer set, each word appeared 32 times in its congruent color, 16 times in one of the (incongruent) colors in the MC set, and 16 times in one of the (incongruent) colors in the MI set (the item-specific proportion of congruent items was thus 50%).

Thus, for the transfer colors, incongruent items were of two types (see the bottom rows in Table 2): 1) incongruent items appearing in MC words (in light gray in Table 2, e.g., RED in yellow), and 2) incongruent items appearing in MI words (in dark gray in Table 2, e.g., WHITE in yellow). These incongruent items were matched on contingency (both had the same low probability for the corresponding words) and on color-specific conflict frequency (since they used the same colors), with the only difference between them being word-specific conflict frequency. Similarly, for the transfer words, incongruent items were also of two types

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[2] A regular ISPC effect in both latencies and error rates was also observed when collapsing all incongruent trials. The congruency effect was larger for MC stimuli (latencies: 140 ms; error rates: 3.58%) than for MI stimuli (latencies: 56 ms; error rates: 2.13%).

(see the right-hand columns in Table 2): 1) incongruent items appearing in MC colors (in light gray in Table 2, e.g., BLACK in blue), and 2) incongruent items appearing in MI words (in dark gray in Table 2, e.g., BLACK in green). These incongruent items were matched on contingency (both had the same low probability for the corresponding words) and on word-specific conflict frequency (since they used the same words), with the only difference between them being color-specific conflict frequency.

Overall, there were 384 items (160 congruent and 224 incongruent). The assignment of each set to the MC, MI, or transfer condition was counterbalanced across participants, as was the assignment of the possible color-word combinations in the transfer set.

Procedure It was the same as in Experiment 1.

Table 2: Template for the Frequency of Color-Word Combinations in Experiment 2.

		Word					
		MC words		MI words		Transfer words	
Color		RED	BLUE	WHITE	GREEN	YELLOW	BLACK
MC colors	Red	46	2			16	
	Blue	2	46				16
MI colors	White			2	46	16	
	Green			46	2		16
Transfer colors	Yellow	16		16		32	
	Black		16		16		32

Results and Discussion

The data treatment was the same as in Experiment 1. Prior to the analyses, invalid trials due to technical failures and responses faster than 300 ms or slower than 2000 ms (accounting for .9% of the data) were discarded.

To examine adaptation to word-specific conflict frequency, we contrasted incongruent items in transfer colors appearing in MC words vs. MI words (i.e., the light gray-dark gray contrast in the bottom rows in Table 2). A paired-samples t-test revealed no difference in the latencies (MC = 792 ms; MI = 790 ms), *t*(71) = .26, *SE* = 6.19, *p* = .798, η_p^2 = .001, although MC words did produce significantly more errors (4.51%) than MI words did (3.10%), *t*(71) = 2.15, *SE* = .007, *p* = .035, η_p^2 = .061. This latter result is consistent with the idea that interference is handled better for stimuli that, being frequently associated with conflict, favor focused attention to task-relevant information.

To examine adaptation to color-specific conflict frequency, we contrasted incongruent items in transfer words appearing in MC colors vs. MI colors (i.e., the light gray-dark gray contrast in the right-hand columns in Table 2). Latencies were significantly longer for MC colors (799 ms) than for MI colors (777 ms), *t*(71) = 3.54, *SE* = 6.22, *p* = .001, η_p^2 = .150. There was also a similar tendency in the error rates (MC = 4.20%; MI = 3.23%), albeit nonsignificant, *t*(71) = 1.38, *SE* = .007, *p* = .171, η_p^2 = .026. These results are also consistent with a process of adaptation to conflict frequency.[3]

Overall, because the conditions being contrasted were matched on contingency, these results replicate the finding of Experiment 1 that processes of adaptation to item-specific conflict frequency can be observed independently of contingency learning. Furthermore, they suggest that these control processes may mainly use conflict frequency information derived from the color dimension, although evidence from the error data does suggest that conflict frequency information derived from the word dimension also has relevance.

General Discussion

In recent years, several phenomena traditionally interpreted as expressions of control processes have been re-interpreted invoking more general processes such as contingency learning (for reviews, see Schmidt, 2013b, 2019). Jacoby et al. (2003) themselves recognized that the ISPC effect they obtained in the Stroop task (i.e., the finding that MC items elicit larger congruency effects than MI items intermixed in the same list) was compatible with at least two processes: on the one hand, a process of adaptation to item-specific conflict frequency whereby recognition of specific stimuli would regulate the engagement of appropriate control processes; on the other hand, a contingency-learning process whereby words are used to anticipate their most likely response. Subsequent work in the ISPC paradigm (e.g., Schmidt, 2013a) has led researchers to conclude that contingency learning may be the only process involved in the ISPC effect, at least in situations, such as the one originally examined by Jacoby et al. (2003), in which contingency learning is a viable option (Bugg & Hutchison, 2013).

In the present research, we reported evidence that challenges that conclusion. Using an ISPC paradigm modelled after Schmidt (2013a), in Experiment 1 we isolated the process of adaptation to item-specific conflict frequency from the process of contingency learning by examining incongruent items matched on contingency but associated with either frequent conflict (MI stimuli) or infrequent conflict (MC stimuli) in a way that avoided a confound in Schmidt's experiment. Consistent with the idea that MI stimuli would favor focused attention to task-relevant information (thus reducing interference from incongruent task-irrelevant information) whereas MC stimuli would favor relaxed attention (thus increasing interference from incongruent task-irrelevant information),

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[3] Again, these results were observed in the presence of a regular ISPC effect in both latencies and error rates. The congruency effect was larger for MC stimuli (latencies: 133 ms; error rates: 3.66%) than for MI stimuli (latencies: 46 ms; error rates: .30%).

latencies on the critical incongruent trials were shorter for the former than for the latter.

These results were obtained in a situation in which, unlike that examined by Schmidt (2013a), words and colors always produced convergent signals for adaptation to conflict frequency (e.g., all MC stimuli in Experiment 1 combined MC colors and MC words, favoring a relaxation of attention). Because the situation examined by Schmidt (2013a) was one in which words and colors produced divergent signals for adaptation to conflict frequency for some stimuli (e.g., some MC words appeared in MI colors), the contrast between Schmidt's (2013a) failure to obtain an effect of adaptation to item-specific conflict frequency and the results of the present Experiment 1 suggests that conflict frequency information derived from both word and color dimensions may be important in the ISPC paradigm (for a more detailed discussion on this point, and for more information on Experiment 1 in general, see Spinelli & Lupker, 2020a).

In Experiment 2, we examined this issue by dissociating the potential effects of adaptation to word-specific and color-specific conflict frequency for a set of critical incongruent stimuli. Similar to Experiment 1, these incongruent stimuli were matched on contingency, thus excluding contingency learning as a viable explanation for any potential differences. A clear effect of adaptation to color-specific conflict frequency was obtained, with some evidence from the error data suggesting that adaptation to word-specific conflict frequency concurrently occurred. Individuals would thus be able to adjust attention in response to both the conflict frequency associated with a color and, to some extent, the conflict frequency associated with a word.

Overall, these results not only disconfirm the view, proposed by the contingency learning account of the ISPC effect (Schmidt & Besner, 2008), that this effect is entirely attributable to contingency learning (a conclusion that seems applicable to other proportion-congruent effects for which a contingency-learning explanation has been proposed, e.g., the list-wide PC effect: Bugg, 2014; Spinelli & Lupker, 2020b; Spinelli, Perry, & Lupker, 2019). These results also pose a challenge to control accounts that negate a role for control processes in the type of situations examined in the present research, i.e., situations in which contingency learning is a viable alternative to adaptation to item-specific conflict frequency (Bugg & Hutchison, 2013). Adaptation to the frequency of conflict specific to individual stimuli appears to be a process that humans use even in those situations (see also Spinelli et al., in review). Further, this process appears to largely rely on conflict frequency information derived from the task-relevant dimension (i.e., the color) rather than the task-irrelevant dimension (i.e., the word). This idea contrasts with the characterization of the ISPC effect initially offered by Jacoby et al. (2003), a characterization in which the word dimension, rather than the color dimension, was assumed to be decisive in this effect. Future research in the area should allow for a thorough consideration of the implications that the present research has for the understanding of the ISPC effect and processes of adaptation to conflict frequency in general.

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