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Coloring Single Stroop Elements: Reducing Automaticity or Slowing Color Processing?

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ABSTRACT Automaticity theory and the effect of coloring a single element were tested with all or only 1 element colored in Stroop tasks. The 312 participants in 5 experiments indicated stimulus presentation color by key press Experiments 1 and 2 replicated those of D. Besner, J. A. Stoltz, and C. Boutilier (1997) with some changes, and revealed similar results: less Stroop interference with only 1 letter colored. Besner et al. (1997) interpreted the results as indicating that coloring a single letter eliminates automatic reading processes. The cause of that reduction in Stroop interference was investigated in Experiments 3, 4, and 5 using color words, bars, and rectangles. The effect of coloring 1 element was to increase color-naming time by the same amount for congruent and neutral, nonverbal stimuli, but not for incongruent stimuli. The results are interpreted in terms of automaticity theory, and a continuous flow approach to the Stroop effect is presented.

Key words: automaticity, continuous flow model, response competition, Stroop effect

THE STROOP EFFECT has a long history in psychology (MacLeod, 1991). The interference of incongruent color words with color naming has been well documented. The most common theory of the Stroop effect is automaticity (LaBerge & Samuels, 1974)—the idea that reading is an automatic process, whereas color naming is not and requires controlled attention; thus, even with instruction, one cannot avoid processing an incongruent color word. Stroop (1935) showed that after long practice, presentation color could interfere with reading color words, presumably a demonstration that automaticity can be changed.

A second process often considered active in Stroop interference is response competition. Processing incongruent color-word stimuli leads to two color names being available to the observer: one correct (the name associated with the color itself) and one incorrect (the name associated with the incongruent color word; Klein, 1964). One has to determine the source of the names before a correct response can be made. This determination, presumably, requires additional time beyond naming the word or the color.

Recently, Besner, Stoltz, and Boutilier (1997) examined the automaticity hypothesis using stimuli with either all letters colored or a single letter colored. They based their study, in part, on Smith, Theodor, and Franklin's (1983) study of priming, in which Smith et al. found that participants who performed a letter search on a prime before responding to a subsequent target exhibited little or no effect of the prime on lexical decision making. From this, Besner et al. (1997) argued that mental set, not reading automaticity, is responsible for Stroop interference. They reasoned that coloring a single letter in the Stroop task would cause the observer to perform letter-based search on the color words and reduce the effect of automatic reading of words. Automaticity would be lessened by the mental set of searching for the single colored letter. To test this notion they used color words, color pseudohomophones, and pseudowords. They colored either one or all the letters of these letter strings and found that Stroop interference was less or even disappeared with one letter colored both for color words and for color pseudohomophones. They stated that their procedure eliminates reading automaticity under certain circumstances by encouraging analytic letter-based processing.

Besner and Stolz (1999a, 1999b) have extended their findings using different experimental paradigms. In one paradigm, they precued a single colored letter and eliminated Stroop interference (Besner & Stolz, 1999b). In the other paradigm, they separated colored neutral words from congruent and incongruent color words (Besner & Stolz, 1999a). Again, coloring only one letter eliminated Stroop interference.

Another explanation of their results comes from considering the kind of result to be expected if reading automaticity were reduced. Reduction of automaticity should allow better attentional control of reading, thus permitting more attentional resources to be used for color naming. Freeing attentional resources for color naming should make color naming more efficient and reduce the interference of reading a word in the naming a presentation color (Stirling, 1979). According to this analysis, reduction of automaticity should speed up processing of incongruent stimuli but have little effect on congruent stimuli. Therefore, if coloring one letter causes concentration on the letters and not the words, reaction time (RT) to incongruent stimuli should be faster with one letter colored than with all letters colored, but RT to congruent stimuli should not be affected. The results of Besner et al. (1997) were quite different. In all cases, nominal RTs to congruent, neutral, and incongruent color stimuli was slower when only a single letter was colored, with markedly greater slowing of congruent and neutral stimuli than

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incongruent stimuli. Thus, it would appear that coloring a single letter slows processing of congruent and neutral stimuli rather than speeding processing of incongruent stimuli.

To test these conclusions, I replicated Experiment 1 of Besner et al. (1997) and conducted four additional experiments, to determine the cause of slower processing when a single letter is colored.

EXPERIMENT 1

The present Experiment 1 replicated Experiment 1 of Besner et al. (1997). Stroop interference was measured for incongruent stimuli using congruent stimuli as the baseline. Color words and color pseudohomophones were used.

Method

All aspects of the method are identical to Experiment 1 of Besner et al. (1997) with the exception of the response keys used.

Participants

Sixty-four Central Michigan University undergraduates participated for course credit. They were tested in groups of four or fewer.

Stimuli

Stimulus words were four color words (red, green, blue, and yellow) and four color pseudohomophones (wred, grene, bloo, and yeloe). All were displayed in lower case on Dell Optiplex 133 computers with 15″ VGA displays. The stimuli were colored red, green, blue, or yellow. The experiment was programmed in MEL 2 (Schneider, 1988) using RGB codes (42, 0, 0), (0, 42, 0), (0, 0, 42), and (63, 63, 21), respectively.

Procedure

Participants were instructed to respond to the color of the stimuli by pressing the appropriate key and to ignore any words they saw. The keys 1, 2, 9, and 0 were covered with red, blue, yellow, and green stickers. On half of the trials, the entire stimulus appeared in red, green, blue, or yellow. On the other half of the trials, only a single letter was colored; the others were presented in gray (42, 42, 42) The position of the colored letter was chosen randomly. Participants were given 72 practice trials with feedback for errors, followed by 288 data collection trials presented without feedback. Stimulus types were randomized and rotated throughout all conditions.

Results and Discussion

RTs by stimulus type, color-word congruence, and number of letters colored are reported in Table 1. When all letters were colored and when only one letter was colored, both words and pseudohomophones showed significant Stroop interference, and Stroop interference was significantly less when one letter was colored than when all letters were colored. When all letters or only one letter was colored, there was significantly less Stroop interference for pseudohomophones than for words. These results occurred because although RTs to congruent stimuli were about the same for words as for pseudohomophones, RTs to incongruent stimuli were significantly less for pseudohomophones than for words. Besner et al. (1997) attributed the faster RT for incongruent pseudohomophones to their less-than-precise correspondence to color words.

Before analysis, outliers were reduced using van Selst and Jolicoeur's (1994) nonrecursive procedure with moving criterion, which was applied to the RT of each condition for each participant. The procedure excludes RTs approximately 2.5 *SD* above the condition mean. This procedure was used in all five experiments to reduce outliers. In Experiment 1, 2.2% of correct RTs were excluded as outliers. Error rates were quite low in this experiment—below 2.5% for each condition. Correlations between RT and error rate were calculated for each participant. The mean correlation ($M = 0.123$) was significantly positive, $t(63) = 2.65$, $p < .01$, indicating no speed–accuracy tradeoff because shorter RTs were accompanied by fewer errors.

RT by stimulus type (word or pseudohomophone), color-word congruence (congruent or incongruent), and number of letters colored (one or all) was analyzed using a fully repeated-measures analysis of variance (ANOVA). Huynh-Feldt Epsilon for each factor was 1.00. The analysis showed that RT was faster to congruent stimuli than to incongruent stimuli, $F(1, 63) = 171.48$, $p < .001$, $MSE = 2260.19$. RT was also faster with all letters colored than with one letter colored, $F(1, 63) = 112.11$, $p < .001$, $MSE = 973.36$. RT to pseudohomophones was faster than RT to color words, $F(1, 63) = 6.93$, $p < .011$, $MSE = 1354.07$. Interactions between stimulus type and color-word congruence, $F(1, 63) = 13.34$, $p < .001$, $MSE = 902.22$, and between color-word congruence and the number of elements colored, $F(1, 63) = 14.40$, $p < .001$, $MSE = 1168.19$, were revealed in this analysis. Interactions between stimulus type and number of elements colored, $F(1, 63) = 3.53$, $p < .065$, $MSE = 957.78$, and among stimulus type, color-word congruence, and the number of elements colored, $MSE = 854.78$, were not significant. This pattern of results replicates those obtained by Besner et al. (1997). The RT data were further analyzed using Loftus and Masson's (1994) method for calculating confidence intervals and critical differences with repeated-measures data.

The fact that congruent and incongruent words and pseudohomophones were responded to more slowly when only one letter was colored has implications for

TABLE 1
RT, Stroop Interference, and Congruency Loss for Congruent and Incongruent Color-Word and Nonword Stimuli With All or One Letter Colored in Experiments 1 and 2

Color-word relation	Letters colored	Experiment 1			Experiment 2			Congruency loss[a]	
		Words	Nonwords[b]	Diff.	Words	Nonwords[c]	Diff.	Words	Nonwords
Congruent	All	662	659	3					
	One	698	703	5					
	Slowing	36*	44*						
Incongruent	All	739	714	15*	717	701	16*	22*	13*
	One	750	738	12 *	740	728	12*	10	10
	Slowing	11*	24*		23*	27*			
Stroop interference	All	77*	55*	22*	55*	42*	13*		
	One	52*	35*	17*	42*	25*	17*		
	Reduction	25*	20*		13*	17*			

Note. RT = reaction time. Diff. = difference. Critical differences in RT: Experiment 1 10.35 ms. Experiment 2: 10.7 ms. between Experiments 1 and 2 10.87 ms.
[a]Increase in RT to incongruent stimuli associated with the presence of congruent stimuli for comparable stimuli in Experiment 2 and Experiment 1. [b]In Experiment 1, nonwords were pseudohomophones. [c]In Experiment 2, nonwords had the same first two letters as color names.
*$p < .05$.

the view that single colored letter presentation reduces automaticity—namely, they suggest that single letter coloring may not reduce automaticity. If single letter coloring reduced automaticity of reading, RT to incongruent stimuli would be faster, not slower, and RT to congruent stimuli would not be affected. Therefore, the experiment shows no effect of single letter coloring on automaticity. Instead, it shows that the effect of coloring one letter is to slow processing. Furthermore, the reduction in Stroop interference for pseudohomophones presented with one letter colored appears to be mainly the result of a slower response to congruent stimuli, rather than a faster response to incongruent stimuli—again a result not supporting a claim of reduced reading automaticity.

The results also show that although RTs to incongruent pseudohomophones were significantly faster than RTs to incongruent color words, incongruent pseudohomophones still yielded significant Stroop interference. This result raises some questions about the operations of automaticity in processing these stimuli. For example, Tzelgov, Henik, Sneg, and Baruch (1996) argued that two types of automaticity are possible; one is phonologically mediated, whereas the other type is based on direct access of the visual pattern of the word to memory. Jared, Levy, and Rayner (1999) argued that for skilled readers, phonology plays a role only in the processing of low-frequency words. The pseudohomophones used in the present study were not only phonologically similar to the color names but also visually similar to three of the words (the first two letters of the pseudohomophones were the same as the color names). In the other case, wred, the color word was contained within the pseudohomophone. If the visual pattern of the word were the only cause of interference, then pseudohomophones, which have less than perfect orthographic similarity to color words, should cause little interference with color naming; yet they do cause interference. The present results indicate that the interference may be operating at a stage of cognition at which homophonic activation produces results similar to those caused by the actual word—that is, after phonological mediation.

EXPERIMENT 2

Experiment 1 and the first experiment of Besner et al. (1997) show that phonological similarity produces Stroop interference. Tzelgov et al. (1996) and Jared et al. (1999) both indicated that orthographic mediation is more common than is phonological mediation. In the present experiment, I tested the limits of orthographic similarity necessary to cause Stroop interference when phonological similarity is low. Besner et al. (1997), in their second experiment, used pronounceable nonword letter strings orthographically similar to color words (pseudowords) paired congruently. They found Stroop interference with all letters colored, but not with one letter colored, and claimed that their results showed that only the first two letters of pseudowords must match the color names in order for Stroop interference to occur. They also claimed that their pseudowords were neutral stimuli. In Experiment 2, the same pseudowords were paired incongruently rather than congruently. If the pseudowords are neutral stimuli, then whether paired congruently or incongruently, they should be processed as quickly as congruent stimuli. If, on the other hand, they are similar enough to color words to produce interference, RT to incongruently paired pseudowords should be comparable to that of incongruent stimuli. Such a result would indicate the action of automatic mediation based on orthography rather than on phonology, even with orthographic similarity limited to the first two letters of the word.

The present experiment also tested the effect of expectancy on processing incongruent stimuli. If the pseudowords paired incongruently act as incongruent stimuli, then only incongruent stimuli will be presented. If expectancy or set plays a role in incongruent processing, then these stimuli should be processed faster than the comparable stimuli in Experiment 1.

Method

Participants

Participants were 64 Central Michigan University students who were given course credit for their participation.

Stimuli

The stimuli were the color words red, green, blue, and yellow, and the pseudowords ret, grend, blat, and yenile, presented as incongruent stimuli.

Procedure

The procedure was the same as that used in Experiment 1 except that there were 36 rather than 72 practice trials and 144 rather than 288 data collection trials.

Results and Discussion

A comparison of RTs to incongruent words, pseudohomophones, and pseudowords in Experiments 1 and 2 is shown in Table 1. With RT to congruent stimuli in Experiment 1 as the baseline, Stroop interference could be calculated for incongruent stimuli in Experiment 2. When one or all letters were colored, there was significant Stroop interference for both incongruent words and pseudowords in Experiment 2. When one or all letters were colored, RT to pseudowords was significantly less than RT to color words. For both stimulus types, single colored letter presentation led to slower processing than did coloring all letters. With all letters colored, RT was less in Experiment 2 than in Experiment 1. Thus, with all letters colored, but not with just one, there was a congruency loss, a reduction in incongruent processing speed when a congruent (or neutral) stimulus was present.

Use of van Selst and Jolicoeur's (1994) nonrecursive moving criterion procedure resulted in elimination of 2.12% of correct RTs as outliers. Error rates were very low in this experiment, less than 2% for each condition. Correlations between RT and error rate were calculated for each participant. The mean correlation ($M = 0.09$) was not significant, indicating no speed–accuracy tradeoff. RT by stimulus type (word or pseudoword) and number of letters colored (one or all) were analyzed using a repeated-measures ANOVA. Huynh-Feldt Epsilons for each condition were 1.00. There was a main effect for the number of letters colored, $F(1, 63) = 55.91$, $p < .001$, $MSE = 695.41$, and for stimulus type, $F(1, 63) = 11.65$, $p < .001$, $MSE = 1113.79$. The interaction between stimulus type and number of elements colored ($MSE = 912.60$) did not have a significant effect on RT. Additional data analysis was accomplished using Loftus and Masson's (1994) method for calculating confidence intervals and critical differences.

Because with all letters colored pseudowords produced Stroop interference at almost the same level as color words, the present experiment confirms the notion of Tzelgov et al. (1996) of automaticity as a dual mechanism phenomenon using both phonological mediation (Experiment 1) and direct visual pattern perception (Experiment 2).

The results also confirm the notion, expressed by Besner et al. (1997), that expectation or set affects incongruent processing, but with the present results, congruency loss occurred only when all letters were colored. Thus, mental set seems to be an unlikely explanation for the single colored letter effect.

So far, the results of Experiments 1 and 2 suggest that the effect of coloring only one letter is not due to a reduction in automaticity. The next three experiments addressed explanations other than reduced automaticity for single colored letter slowing. Discussion of the results of the three experiments appears after the results of Experiment 5 are presented.

EXPERIMENTS 3, 4, AND 5

If coloring a single letter has an effect on color naming rather than on automatic reading processes, then that effect should be discernible when colors are presented without words. The next three experiments tested this hypothesis. In all three experiments, neutral, nonverbal stimuli consisting of colored bars and rectangles were presented. In Experiment 3, congruent words were the only verbal stimuli presented. In Experiment 4, incongruent words were the only verbal stimuli presented. In Experiment 5, both congruent and incongruent words were presented. Thus, a second purpose of the experiments was to measure the effect of the presence of incongruent stimuli on processing of congruent and neutral stimuli with one and with all elements colored.

Method

Only exceptions to the method of Experiment 1 are described here.

Participants

In Experiments 3, 4, and 5 there were 64, 57, and 63 participants, respectively.

Stimuli

The stimuli used included single colored bars (bars were produced by individual rectangles, 11 pixels wide by 12 pixels high; there was no space between elements of the bars) approximately the same length as color words, and rows of discrete color rectangles (7 pixels wide by 12 pixels high) approximately the same length as color words. Additionally, in Experiment 3, congruent color-word stimuli were included. In Experiment 4, incongruent color-word stimuli were included. In Experiment 5, both congruent and incongruent color-word stimuli were included. The four colors and color words used in Experiment 1 were used here.

Procedure

There were 36 practice trials in all three experiments and 216 data collection trials in Experiments 3 and 4. There were 288 data collection trials in Experiment 5.

Results of Experiment 3: Congruent and Neutral Stimuli

The results of all three experiments are reported in Table 2. For all three types of stimuli, coloring only one element produced significantly slower RTs than coloring all the elements. Within each level of the number of elements colored, there were no significant differences in RTs among the three stimulus types, color bars, color rectangles, and congruent color words. These results suggest that single element coloring slows neutral, nonverbal stimuli about as much as it slows congruent color-word stimuli.

Use of van Selst and Jolicoeur's (1994) nonrecursive moving criterion procedure resulted in elimination of 1.94% of correct RTs as outliers. Error rates were very low in this experiment, less than 3.2% for each condition. Correlations between RT and error rate were calculated for each participant. The mean correlation ($M = 0.08$) was not significant, indicating no speed–accuracy tradeoff. RT by stimulus type (bars, rectangles, or congruent color words) and the number of elements colored (one or all) was analyzed using a fully repeated-measures ANOVA. The number of elements colored, $F(1, 63) = 77.94$, $p < .001$, $MSE = 917.36$, Huynh-Feldt Epsilon = 1.00, but not stimulus type, $F(2, 63) = .94$, $p < .397$, $MSE = 772.60$,

TABLE 2
RT, Stroop Interference, and Incongruency Loss for Congruent, Neutral, and Incongruent Color-Word Stimuli With All or One Element Colored in Experiments 3, 4, and 5

Color-stimulus relation	Elements colored	Experiment 3	Experiment 4	Experiment 5	Incongruency loss[a] between Experiments 3–5
Congruent	All	662		677	17*
	One	689		694	12
	Slowing	27*		17*	
Neutral rectangles	All	657	666	674	17*
	One	689	699	693	4
	Slowing	32*	33*	19*	
Neutral bars	All	659	664	668	9
	One	682	685	692	10
	Slowing	23*	21*	24*	
Incongruent	All		743	754	
	One		754	751	
	Slowing		11	4	
Stroop interference: neutral	All		78*	83*	
	One		63*	58.5*	
	Reduction		15*	24 5*	
Stroop interference: congruent	All			75*	
	One			50*	
	Reduction			25*	

Note. RT = reaction time. Critical differences: Experiment 3: 9.67 ms, Experiment 4: 12.07 ms, Experiment 5: 10 81 ms, between Experiments 3 and 5. 14 50 ms.
[a]Increase in RT to congruent or neutral stimuli associated with the presence of incongruent stimuli for comparable stimuli in Experiments 3 and 5
*$p < .05$.

Huynh-Feldt Epsilon = 1.00, had a significant effect on RT. The interaction between stimulus type and the number of elements colored did not have a significant effect on RT, $F(1.88, 119.0) = 1.03$, $p < .36$, $MSE = 733.45$, Huynh-Feldt Epsilon = .940. Additional data analysis was accomplished using Loftus and Masson's (1994) method for calculating confidence intervals and critical differences.

Results of Experiment 4: Neutral and Incongruent Stimuli

For bars, rectangles, and incongruent color words, coloring only one element produced significantly slower RTs than coloring all the elements. Again, as in Experiment 3, within each level of the number of elements colored there were no significant differences in RTs among the two neutral stimulus types (color bars and color rectangles). Incongruent color words were processed significantly more slowly than neutral stimuli, indicating Stroop interference, and that interference was significantly greater with all letters colored than with one letter colored.

Use of van Selst and Jolicoeur's (1994) nonrecursive moving criterion procedure resulted in elimination of 2.09% of correct RTs as outliers. Error rates were very low in this experiment, less than 2.5% for each condition. Correlations between RT and error rate were calculated for each participant. The mean correlation ($M = 0.08$) was not significant, indicating no speed–accuracy tradeoff. RT by stimulus type (bars, rectangles, or incongruent color words) and the number of elements colored (one or all) was analyzed using a fully repeated-measures ANOVA. Both the number of elements colored, $F(1, 56) = 35.26$, $p < .001$, $MSE = 1175.21$, Huynh-Feldt Epsilon = 1.00, and stimulus type, $F(1.56, 89.88) = 91.49$, $p < .001$, $MSE = 2670.01$, Huynh-Feldt Epsilon = .785, had significant effects on RT. The interaction between stimulus type and the number of elements colored also had a significant effect on RT, $F(1.93, 108.18) = 3.24$, $p < .044$, $MSE = 1017.18$, Huynh-Feldt Epsilon = .966 Additional data analysis was accomplished using Loftus and Masson's (1994) method for calculating confidence intervals and critical differences.

Results of Experiment 5: Congruent, Neutral, and Incongruent Stimuli

For bars, rectangles, and congruent color words, but not incongruent color words, coloring only one element produced significantly slower RTs than coloring all the elements. Within each level of the number of elements colored, there were no significant differences in RTs among the congruent and neutral stimulus types. Incongruent stimuli were processed significantly more slowly than congruent stimuli, indicating Stroop interference, and there was significantly less Stroop interference with one letter colored than with all letters colored. A similar comparison was made using mean RT to neutral stimuli as the baseline. Similar results were found—significant Stroop interference that was significantly reduced by coloring one element.

Use of van Selst and Jolicoeur's (1994) nonrecursive moving criterion procedure resulted in elimination of 2.11% of correct RTs as outliers. Error rates were very low in this experiment, less than 2.9% for each condition. Correlations between RT and error rate were calculated for each participant. The mean correlation ($M = 0.05$) was not significant, indicating no speed–accuracy tradeoff. RT by stimulus type (bars, rectangles, congruent color words, or incongruent color words) and the number of elements colored (one or all) was analyzed using a fully repeated-measures ANOVA Both the number of elements colored, $F(1, 62) = 29.06$, $p < .001$, $MSE = 1008.20$, Huynh-Feldt Epsilon = 1.00, and stimulus type, $F(2.51, 155.89) = 97.07$, $p < .001$, $MSE = 1827.57$, Huynh-Feldt Epsilon = .838, had a significant effect on RT. The interaction between stimulus type and the number of elements colored also had a significant effect on RT, $F(2.92, 181.60) = 5.63$, $p < .001$, $MSE = 903.01$, Huynh-Feldt Epsilon = .976. Additional data analysis was accomplished using Loftus and Masson's (1994) method for calculating confidence intervals and critical differences.

General Results of Experiments 3, 4, and 5

Comparisons of RTs to color bars and rectangles and congruent and incongruent words in Experiments 3, 4, and 5 are reported in Table 2. Further analyses were conducted using the estimated variance of the mean difference between comparable means in Experiments 3, 4, and 5 (Loftus & Masson, 1994). Overall, the effect of coloring a single element was to increase congruent and neutral RTs by about 24 ms without any significant effect on incongruent RT. Therefore, there was a significant reduction in Stroop interference due to coloring a single element.

With all elements colored, RTs to congruent color words and color rectangles were slower when incongruent stimuli were present (Experiment 5) than when only congruent and neutral stimuli were present (Experiment 3). Other than those two instances, in no other cases was there significant incongruency loss.

GENERAL DISCUSSION

The basic question of the present experiments concerns the effect of coloring one element on Stroop processing. Does coloring a single element reduce reading automaticity? Results of those experiments as well as of the experiments of Besner et al. (1997) demonstrate that coloring a single element slows processing of congruent and neutral stimuli more than it slows processing of incongruent stimuli. Furthermore, because coloring one element of nonverbal (neutral) stimuli slows processing at the same rate as it does with congruent color-word stimuli, the most parsimonious explanation for the single colored element effect would be one that had to do with color identification and naming rather than with reading or reading automaticity.

One mode by which coloring one element could slow processing is by making identification of the color more difficult. If only one random element of the stimulus is colored, then the participant must search for the element containing the color. Although the color may pop out, even pop out takes time.

If color identification is slowed by coloring one element, an obvious question occurs: Why does it not slow processing of incongruent stimuli as much as it does congruent and neutral stimuli? All three types of stimuli require it. One kind of model that could fit these results is a continuous flow model (e.g., Coles, Gratton, Bashore, Eriksen, & Donchin, 1985). With this type of model, color processing and verbal processing initially follow separate paths. As each is processing its part of the stimulus, it is also incrementally priming a response. When a preset priming threshold is reached, a response occurs. With congruent or neutral stimuli, only one response is primed, but with incongruent stimuli, two responses are primed; one correct (based on stimulus color) and one incorrect (based on the color word). Thus, to respond correctly to an incongruent stimulus, one must be able to identify the source of the priming, suppress the incorrect primed response, and make the correct primed response. This kind of model can also be applied to the present experiments. If only one element is colored, color processing is slowed by the amount of time necessary to search for and find the color. Verbal processing, on the other hand, should occur at the same rate whether one or all elements are colored. The best estimate of the time required for color processing and response is RT to neutral, nonverbal stimuli, because it is not contaminated by reading processes. Coloring one rather than all elements adds about 25 ms to RT to neutral stimuli. RT to congruent stimuli and the increase in RT due to single letter coloring is approximately the same as with neutral stimuli; thus, it appears that RT to congruent stimuli is dependent on color processing rather than on reading processing. This conclusion appears counterintuitive because with congruent stimuli both processes are priming the same response. If there are no incongruent stimuli present in the stimulus set, the first response that is primed could be used. Because congruent and neutral stimuli are processed at about the same rate, however, most likely the observer waits until the color processing primes the response adequately before responding.

Although the idea of color search is an adequate explanation for increased RT when single elements of congruent and neutral stimuli are colored, by itself it does not explain the lesser increase in RT when single elements of incongruent stimuli are colored. For that explanation, an additional element is needed. The extent to which RT to incongruent stimuli exceeds RT to neutral stimuli is a measure of the time required for that additional element. The additional element is most likely related to verbal processing, not color processing, and yet it cannot be processing of the color word itself. An obvious explanation is that because color and verbal processing prime different responses, the response primed by the verbal stimulus must be suppressed, and that suppression takes time. If color and verbal processing are relatively independent of each other, the time to process the color word and suppress the verbally primed response will be the controlling factors in RT to incongruent stimuli, whether one or all elements are colored. In either case, color processing will be complete before the verbal response has been repressed. Note that if automatic reading processes were suppressed, there would be no word-based response to be suppressed, and RT to incongruent stimuli would be reduced.

Besner et al. (1997) stated that the mental set caused by the presence of congruent words, congruency loss, has an important effect on Stroop processing. The present experiments revealed an effect of mental set on processing only with all letters colored. There was both a congruency effect (the effect of congruent stimuli on processing of incongruent stimuli; Experiment 2) and an incongruency effect (the effect of the presence of incongruent stimuli on processing of congruent and neutral stimuli; Experiments 3 and 5). This finding is consistent with many other results (e.g., Nealis, 1973). When incongruent stimuli were present, congruent stimulus processing was slowed. More interestingly, processing of some nonverbal stimuli was also slowed, indicating that the slowed processing can occur without postulating a word-related processing step. Nealis attributed the slowing of congruent processing to preparation for response competition.

The ideas of separate color and verbal processing and suppression of incorrect verbal responses suggest an explanation for incongruency loss. On the one hand, because incongruency loss occurs not only with congruent stimuli, but also with neutral, nonverbal stimuli, automatic reading processes cannot be the major cause. On the other hand, it seems unlikely that color processing is the culprit. Instead, the most likely cause is preparation for the occurrence of incongruent stimuli. That preparation undoubtedly includes preparation for suppression of the word-based response. Presumably, readiness for dealing with two different primed responses necessitates longer pre-response processing. That preparation consists of requiring enough priming to identify the stimulus source adequately before the response occurs. Note, however, that only preparation, not actual response suppression, is needed. Nonetheless, processing incongruent stimuli requires not only preparation for, but also actual suppression of, incorrect responses. Thus, according to this kind of model, Stroop interference is the additional time needed to actually suppress an incorrect response.

In summary, the reduction in Stroop interference seen with stimuli with a single element colored is best explained not by a reduction in automaticity, but instead by an increase in color processing time. As shown by the increase in processing time caused by coloring a single element of neutral, nonverbal stimuli, the increase in color processing time is unrelated to reading automaticity. It is most likely related to additional time caused by visual search for the color.

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