The locus of interference in the Stroop and related tasks*

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Perceptual conflict and response competition interpretations of studies of color-word interference are briefly considered, and a study of the effect of semantic factors on color-word interference in a color comparison task is reported. It is concluded that the locus of interference is after, and not during, the processing of the word component of color-word stimuli.

In the Stroop color-word task, one finds that it is easier to name the color of a stimulus when the stimulus is a color patch than when it is a written word. A number of attempts have been made to account for this phenomenon, and, though they have enough similarities to defy classification, they may be conveniently grouped according to whether the interference is characterized as being due to perceptual conflict or to response competition, i.e., conflict between encoding processes or between the outcomes of encoding processes. Perceptual conflict explanations (e.g., Hock & Egeth, 1970) state that processing of the word disrupts or otherwise delays the processing of the color, presumably because some sort of limited processing capacity is involved (cf. the "single-channel operation" hypothesis, Welford, 1967), and that word recognition is prior to color naming (word reading is faster than color naming, Lund, 1927). Accordingly, an important determinant of interference would be the speed with which the color and word components of Stroop items are processed. This appears to be the case, judging from findings that indicate that the legibility or identifiability of the word and the clarity of the color influence the amount of interference produced (Bakan & Alpers, 1967; Dyer, 1970; Gumenik & Glass, 1970). Also consistent with this view is the fact that interference may operate in the opposite direction in tasks where word processing may take longer than color processing. Thus, Uleman and Reeves (1971) report slower scanning for color names when the list scanned consisted of Stroop items than when the list consisted of color names written in black. This makes sense,

since color identification (as opposed to color naming) appears to be faster than word reading (Lund, 1927). A preliminary attempt by the first author at replicating and extending the Uleman-Reeves study showed that their results cannot be attributed solely to greater legibility of the word when written in black, for a similar outcome was obtained when the single-color lists were in other colors. Complete elimination of interference from the word would also be expected in this task when S scans through Stroop items for color targets, and this too was reported by Uleman and Reeves. However, Pritchatt (1968), who had his Ss match the colors of Stroop items by pressing colored keys, found that though interference from the word was reduced it was not completely eliminated. It is possible that the remaining interference was due to a tendency for his Ss to name the colors covertly instead of directly responding to the keys. Azkoul (unpublished study) had his Ss sort cards into bins according to the color of the stimuli on the cards. For half the Ss, the bins were labeled with color names; for the others, the labels were colored grids. When the stimuli were rows of colored letters (e.g., NNN), there was no difference in sorting times whether the bins were labeled with colors or words. With the color-word stimuli (e.g., "red" in blue ink), worse performance was produced initially with slowest times and more errors when the bins were labeled with words. However, by the time the sixth deck was reached in all conditions, all differences in sorting times were reduced to the point of being statistically unreliable. These results suggest that, with practice, Ss came to identify bin locations with particular colors, thus bypassing the need for covert color naming, and as a consequence avoided interference from the word. Perhaps with more practice a similar elimination of color-word interference would have occurred in Pritchatt's study.

Covert color naming is also very

likely to have been the basis of the results of Hock and Egeth (1970). They presented their Ss with three types of items: Xs, common verbs, and color names, written in different colors. Target sets of one, two, or three color names were defined by E, and the Ss' task was to indicate with a vocal yes-no response whether or not the color of the stimulus items belonged to the target set. Response times were found to be a linear function of the size of the target set, and, while the slope of this function was not significantly different for the three types of items, the intercept did differ, being least for Xs and greatest for color names. Following Sternberg's (1967) strategy, they attributed the differences in the intercept to differences in the speed of encoding the color component of the three types of stimuli. The nonsignificant interaction between type of stimulus and size of the target set was interpreted as the absence of competition from the verbal component of the stimuli. However, since the target set was defined for S in terms of color names, it seems quite unlikely that S could respond without covertly naming the color of the stimulus, in which case the task reduces to a disguised version of the usual Stroop task. Therefore, it is difficult to see how explanations that apply equally well to the latter would have differential predictions for performance in the former. In the task of Hock and Egeth, "memory examination" could only take place after the name of the color had been determined. Any color-word interference regardless of its origin (i.e., whether a case of perceptual or of response conflict) would therefore occur prior to the memory examination phase and thus affect the intercept and not the slope of the linear function.

Complete elimination of interference from the word component of Stroop items has been reported by Egeth, Blecker, and Kamlet (1969). Their Ss had to decide whether or not both members of a pair of stimuli were of the same color. No difference was found in the speed of responses ("same" and "different") to pairs of color strips and pairs of Stroop items where the words were color names. Since color matching is presumably speedier than word reading (and the close proximity of the colors would have obviated the need for covert color naming), color matching would be insulated from interference by the word-encoding process. When the words spelled SAME and DIFF, interference was found, a result not consistent with the explanation just given for the lack of

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interference when the words were color names. Egeth et al suggest that perhaps the words were recognized (i.e., processed) more quickly when they were similar to the responses S was set to make. If this "priming" of word recognition speeds up the processing of the words to the point where word recognition occurs prior to the completion of the color matching, conflict between the processing of the two components of the stimuli could be expected when the responses are "same" and "different" and the words are SAME and DIFF, but not when the words are color names.

The suggestion that there is quicker processing of the words when they are similar to the responses required to the colors is particularly interesting, because without it, perceptual conflict explanations would have difficulty in accounting for results not specifically mentioned thus far in this paper, namely, the influence of semantic and associative factors on color-word interference. Klein (1964) and others have reported that words naming colors interfere much more with color naming than words not naming colors. Scheibe, Shaver, and Carrier (1967) found that words more closely associated with colors, when written in colors they are unrelated to, produce more interference with color naming than words less closely related to colors. There are, however, other findings that do not fit well with a perceptual conflict explanation, even when the suggestion of Egeth et al is incorporated. When words associated with colors are written in those colors, less interference is produced (Dalrymple-Alford, 1972; see also the results of Langer & Rosenberg, 1966). Such findings are more readily handled by response competition explanations, which will now be considered briefly.

Explanations in terms of response competition of color-word interference place the locus of interference at a stage after the word has been processed (cf. Morton, 1969). Of course, interference will occur only when the word is processed before processing of the color is completed, and thus word and color processing times would feature just as importantly in response competition as well as perceptual conflict explanations. Response competition presumably arises because S has to suppress his response to the word in order to make his response to the color. How easily this competition may be overcome would depend on the extent to which the two responses are similar. Thus, while perceptual conflict explanations would relate the Stroop to phenomena indicating

limited processing capacity, response competition would suggest that it has much in common with other effects arising out of verbal interference, e.g., interference effects in verbal learning. In the case of the latter, the same process that sometimes leads to interference may under certain circumstances lead to facilitation of responding. When the word tends to elicit the appropriate response to the color, even though it produces some delay in responding because it has to be suppressed, the delay is partly offset if the word also "primes" the correct response to the color (Dalrymple-Alford, 1972). Facilitation of color naming by bilinguals may also be explained in this way (Dalrymple-Alford, 1968).

We know of no existing study of the Stroop and related tasks that has produced results that could not be accounted for in terms of response competition, unless the competition is postulated to occur only between the (covert) response to the word and the overt response to the color (e.g., the version of response competition set up and knocked down by Treisman and Fearnley, 1969). Even the Hock and Egeth (1970) study, which purported to show that interference was not due to response competition, provides no embarrassment because, since covert color naming was very likely necessary, as mentioned earlier, the basis for response competition was present. The results of the Egeth et al study may just as easily be interpreted in terms of response competition. Color matching may be completed before word recognition, but this in turn may be completed before the response contingent on color matching has been emitted. The latter would therefore be subject to interference from the response to the word, depending on how similar the two were. When the words are color names and the responses are "same" and "different," little interference would be expected. However, when the words are SAME and DIFF, interference with responding would be expected to arise. A perceptual conflict explanation incorporating the Egeth et al suggestion about priming of word recognition would appear also to lead to the same expectations, with one difference. While processing of the words SAME and DIFF could disrupt the color matching process, there is nothing in the hypothesis of perceptual conflict that would lead us to expect SAME, for example, to have a smaller disruptive effect than DIFF when the correct overt response should be "same." A response competition explanation, on the other hand, would lead us to expect more disruptions of responding when the

word elicits the wrong overt response directly or by association. This matter was examined in the study reported below.

METHOD

Subjects

The Ss were 12 male and 12 female U.S. students attending the American University of Beirut.

Materials

Eighteen decks, each consisting of 24 white visiting cards, were prepared. On each card there appeared two identical words, one approximately 6 mm above the other. For six decks (x/j), the "words" were the letter combinations "xzn" and "jdlk." Another six (y/n) had the words "yes" and "no," while the remainder (r/w) had the words "right" and "wrong." Using rubber stamps with letters approximately 4 mm high and red, green, and blue inks, each word pair was printed equally often in the same and in different colors. Thus, for example, one deck consisted of 12 cards with the pairs "yes"-"yes," and 12 with the pairs "no"-"no," and in each case six cards would have the words in the same colors and six with the words in different colors. A fixed ordering was determined for the cards in each deck; the arrangement was random except for restrictions resulting in no two successive cards having identical stimuli and no runs of more than three cards with same-color pairs or with different-color pairs. Besides these 18 decks there were two practice decks. One consisted simply of 24 blank cards. The other consisted of 24 cards sampled from the types of cards used in the 18 experimental decks, so that the six words, "xzn," "jdlk," "yes," etc., were represented equally often, each twice with the colors the same and twice different.

PROCEDURE

The Ss were allocated randomly to one of two groups so that there were six males and six females in each. Instructions to one group were that each card was to be turned over and the response was to be "yes" if the colors of the two words on the cards were the same, and "no" if they were different. Ss were told to work through each deck as quickly as possible without making any errors and, if any were made, they were not to waste time correcting them. They were first given some practice trials turning over the cards of the blank deck. When they seemed sufficiently adept at this, the second practice deck was given and they responded to each card by calling out "yes" and "no," as they considered appropriate. Immediately after this they proceeded

Table 1
Mean Response Times Per Deck (Seconds)

Type of Response	Type of Deck		
	Yes/No	Right/Wrong	xzn/jdlk
Yes-No	21.40	20.07	20.16
Right-Wrong	20.44	21.35	20.10

to the 18 experimental decks. A different order of decks was used for each S. Every three decks included one x/j deck, one y/n deck, and one r/w deck, but, except for this restriction, the ordering was random.

The procedure for the second group was the same except that instead of responding with "yes" and "no," they had to say "right" when the colors matched and "wrong" when they did not.

All Ss were tested individually, and their responses were tape-recorded. From these recordings, the time between the first and last response for each deck was determined to the nearest .1 sec and the errors were noted.

RESULTS

For each S the mean time to respond to each type of deck was determined separately for the first and second halves of the series of trials. (Since very few errors were corrected by the Ss, these times were for nearly the same number of overt responses for all types of deck.) These means were subjected to analysis of variance with type of response (yes-no, right-wrong) and the sex of the S as between-S effects and type of deck and "halves" as within-S effects. The only significant effects were those due to type of deck [$F(2,100) = 7.98$, $p < .01$], "halves" [$F(1,100) = 19.43$, $p < .01$], and the Type of Deck by Type of Response interaction [$F(2,100) = 14.18$, $p < .01$]. There was no significant change with practice in the type of Deck by Type of Response interaction as was indicated by a nonsignificant Halves by Deck by Response interaction ($F = .92$). The Newman-Keuls test revealed no significant overall difference between the y/n and r/w decks ($p > .05$), but these led to significantly slower times than the x/j decks ($p < .01$). The nature of the Type of Deck by Type of Response interaction is fairly clear from the means set out in Table 1. Yes-no response times for the y/n decks were scarcely different from the right-wrong response times for the r/w decks, and both of these were longer than the times for right-wrong responses to y/n and x/j decks and yes-no responses to r/w and x/j decks, all of which were approximately equally fast. This was revealed more

clearly when the y/n and r/w decks were reclassified so that the former with yes-no responding and the latter with right-wrong responding were labeled "high conflict" decks; otherwise they were labeled "low conflict" decks. The x/j decks were grouped together as before and may be regarded as "control" decks. Analysis of variance on the reclassified data produced the same outcome as before except that now the Type of Response by Type of Deck interaction vanished ($F = .74$). The Newman-Keuls test revealed a significant difference ($p < .01$) between the "high conflict" decks on the one hand and the "low conflict" and "control" decks on the other; the latter two were not significantly different ($p > .05$).

The distribution of the total number of errors (over all Ss and all decks) is given in Table 2. No statistical analysis seemed appropriate since the number of errors in the different categories made by each S was very small. The extent to which the pattern of errors was not random is revealed by chi-square values computed for each of the six fourfold classifications that make up Table 2. These values were 41.26, 22.94, and .32 for the y/n, r/w, and x/j decks, respectively, when the responses were yes-no, and 23.45, 53.27, and .97, respectively, for the same decks when the responses were right-wrong. If we are prepared to assume independence of the observations pooled in Table 2, we may test for contingency by comparing these chi-square values with the critical values of 3.841 (5% level) and 6.635 (1% level).

DISCUSSION

Response times show that interference from the words is manifest only when the words are the same as those S uses to announce the outcome of color matching. When the written words are different from the

verbal responses, the latter are made just as quickly as when the words are meaningless combinations of letters. These results are consistent with those of Eggeth et al (1969) and by themselves add no further enlightenment. The error totals for the "high conflict" decks (105 and 103), the "low conflict" decks (62 and 70), and the "control" decks (54 and 50) appear to tell the same story. However, the pattern of errors shown in Table 2 indicates that the effect of the words on the cards was not the same for all cards. This pattern parallels the latency data of Dalrymple-Alford (1972). In the present study, the greatest number of errors occurred when the word conflicted directly with the correct response, while in that study longest response times were found in a corresponding condition (color names in noncongruent colors). In the present study, when the word matched the correct response fewer errors occurred, while in the earlier study faster latencies were obtained (i.e., for color names in congruent colors). Similar parallels may be noted in the case where the word itself may not be the response to the color. Dalrymple-Alford found that color-related words produced slower responding when written in colors they were not related to, but faster times when written in colors they were related to. The pattern of errors in the present study when the words were "yes" and "no" and the responses "right" and "wrong," and vice versa, takes a similar form, that is, if one can assume that "yes" and "right," and "no" and "wrong" are associated pairs. The yes-right association is not implausible since there are verbal contexts in which they are completely substitutable (e.g., when either may be used to indicate to another person agreement with stages of an argument being put forward). The no-wrong association is less obvious, though responses from individuals unacquainted with the present study indicate that the relationship exists. Students at Trent University were asked to indicate which of the words "right" and "wrong" seemed to them to be most naturally related to "no." Eight out of 10 replied "wrong." Of

Table 2
Distribution of Errors (Totals)

Erroneous Response	Word on Card					
	Yes	No	Right	Wrong	xzn	jdlk
Yes	38	12	32	9	12	13
No	7	46	3	18	10	15
Right	29	10	50	8	11	12
Wrong	5	26	7	40	19	12

another 10 individuals who were asked the same question about "yes," all said the associated word was "right." Turning the question around for two further groups of 10 individuals showed that 9 out of 10 felt "no" and "wrong" were related, and 10 out of 10 felt that "yes" and "right" were related. This suggests that interpretation of the present results along the lines suggested by Dalrymple-Alford (1972) for his color naming data is appropriate. It is difficult to see how an explanation simply in terms of perceptual conflict would account for the error data.

By way of conclusion, it may be appropriate to point out that while reference has been made repeatedly to two types of explanations of color-word interference, the explanations to date are little more than suggestions as to where the locus of the interference is. Why the interference occurs is seldom made explicit, and indeed at this stage it may be premature to do otherwise. But if the conflict is a perceptual one, is it due to limited processing capacity being divided among two tasks (color and word perception) or to serial processing of the two inputs with words under some circumstances gaining prior entry and holding up processing of the color? If response competition, is it that the response to

the words makes selection of the appropriate response to the color more difficult, or is it that selection of the response to the color is unaffected but rather there is competition between the two responses at the time when one has to be emitted or passed on to the next stage in the task? The concern of this paper has been not so much with explanations of color-word interference as with the question of the stage at which it occurs, and the conclusion that seems warranted is that the locus of interference is after word recognition has occurred and not before.

REFERENCES

- BAKAN, P., & ALPERSON, B. Pronounceability, attentivity, and interference in the color-word test. *American Journal of Psychology*, 1967, 80, 416-420.
- DALRYMPLE-ALFORD, E. C. Interlingual interference in a color-naming task. *Psychonomic Science*, 1968, 10, 215-216.
- DALRYMPLE-ALFORD, E. C. Associative facilitation and interference in the Stroop color-word task. *Perception & Psychophysics*, 1972, 4, 274-276.
- DYER, F. N. Word reading, color naming and Stroop interference as a function of background luminance. USAMRL Report No. 889, 17 August, 1970.
- EGETH, H. E., BLECKER, D. L., & KAMLET, A. S. Verbal interference in a perceptual comparison task. *Perception & Psychophysics*, 1969, 6, 355-356.
- GUMENIK, W. E., & GLASS, R. Effects of reducing the readability of the words in the Stroop color-word test. *Psychonomic Science*, 1970, 20, 247-248.
- HOCK, H. S., & EGETH, H. E. Verbal

interference with encoding in a perceptual classification task. *Journal of Experimental Psychology*, 1970, 83, 299-303.

KLEIN, G. S. Semantic power measured through the interference of words with color-naming. *American Journal of Psychology*, 1964, 77, 576-588.

LANGER, J., & ROSENBERG, B. G. Symbolic meaning and color naming. *Journal of Personality & Social Psychology*, 1966, 4, 364-373.

LUND, R. H. The role of practice in the speed of association. *Journal of Experimental Psychology*, 1927, 10, 424-433.

MORTON, J. Categories of interference: Verbal mediation and conflict in card sorting. *British Journal of Psychology*, 1969, 60, 329-346.

PRITCHATT, D. An investigation into some underlying associative verbal processes of the stroop color effect. *Quarterly Journal of Experimental Psychology*, 1968, 20, 351-359.

SCHEIBE, K. E., SHAVER, P. R., & CARRIER, S. C. Color association values and response interference on variants of the Stroop test. *Acta Psychologica*, 1967, 26, 286-295.

STERNBERG, S. High speed scanning in human memory. *Science*, 1966, 153, 652-654.

TREISMAN, A., & FEARNLEY, S. The Stroop test: Selective attention to colours and words. *Nature*, 1969, 222, 437-439.

ULEMAN, J. S., & REEVES, J. A reversal of the Stroop interference effect, through scanning. *Perception & Psychophysics*, 1971, 9, 293-295.

WELFORD, A. T. Single channel operation in the brain. *Acta Psychologica*, 1967, 27, 5-22.

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