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The Stroop phenomenon and its use in the study of perceptual, cognitive, and response processes*

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The present review summarizes empirical findings and theoretical views related to the Stroop color-word test. Experimental findings were emphasized in contrast to the results of correlational studies, and the bulk of the material was produced since the 1966 review of Jensen and Rohwer. One purpose of the review was to illustrate use of the Stroop paradigm as a tool for the study of other psychological processes. The incompleteness, and in some cases the inappropriateness, of existing explanations of the Stroop phenomenon also were discussed.

In the Stroop color-word test (Stroop, 1935), a large disruption and delay in color naming occurs for a card of color patches that are shaped to spell incongruent color names. The most important score on this test is the difference between the time to name colors on this card and the time to name colors on a card where the patches are rectangles, asterisks, or words that are not incongruent color names. Jensen and Rohwer (1966) have provided an extensive review of the Stroop literature including methodology, research findings, and theoretical considerations. Much of their review deals with individual differences in performance as these relate to other performance and personality measures. The present review is concerned primarily with two other classes of studies: (1) experiments which were designed to extend knowledge of the Stroop phenomenon itself and (2) experiments which utilized the phenomenon in some form as a tool to study other problems such as word meaning, semantic satiation, hemispheric differences, and bilingual language organization. With a few notable exceptions, these studies have appeared since the Jensen and Rohwer (1966) review was prepared. Following those sections of this paper devoted to each of the above topics, a final section attempts to integrate the various experimental and theoretical contributions and thus provide a current perspective on the locus and mechanism of Stroop interference.

STUDIES OF THE STROOP PHENOMENON

Anomalous situations have long provided much of man's scientific knowledge. For example, rifts in the earth's crust have been critical for development of geology. Similarly, psychopathology has been the basis for theories of personality. In experimental psychology, a great deal of attention has been focused on optical illusions in the expectation that their understanding would aid our understanding of normal visual and perceptual processes. For this reason, the anomalous color naming of the Stroop test should make it an important means for increasing our understanding of the normal processes of reading, stimulus identification, and stimulus naming that either disrupt or are disrupted in the Stroop test. This point of view may not have been explicitly stated, but a substantial number of investigations have been conducted to elucidate the conditions that produce the Stroop phenomenon.

Color-Word Configurations that Produce Interference

On the critical interference card of the traditional form of the Stroop test, color patches in the form of words denoting color names are printed with the color of the patch different from the color denoted by the word. A series of patches in different colors appears on the card, and usually the basic datum is the total time required to name the colors of all patches on the card. This format has been highly successful in the production of interference, i.e., a delay of color naming, and relatively little deviation from this methodology has occurred in the history of the Stroop test. However, one small but important departure has been the presentation of single Stroop stimuli and measurement of the latency of the single color-naming response. This procedure apparently was first utilized by Dalrymple-Alford and Budayr (1966). Sichel and Chandler (1969), using a similar procedure, found reliable differences in response latency between conditions with incongruent color names and with nonword color patches. They also included congruent combinations of words and colors in their sequences of individual stimuli and found faster naming with these than with the incongruent combinations. The measurement of single response latencies has allowed a finer analysis of responses and is critical for some of the uses of the Stroop paradigm in studying other psychological phenomena which are described later in this review.

Both the traditional card of patches and the individual

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stimulus procedure involve the closest possible integration of the color and word aspects with actual formation of the word with the color. Other studies have addressed themselves either directly (Kamlet & Egeth, 1969; Dyer & Severance, in press; Dyer, 1972b) or incidentally (Grand, 1968) with the question of whether interference to color naming occurs with other word/color configurations. Two investigations used names printed in a neutral color on colored rectangles with the task being to name the color of the rectangle. For Kamlet and Egeth (1969), the words were printed in white and were names of colors that differed from the color of the rectangles. Times to name the rectangle color for a series of such stimuli were delayed relative to naming colored rectangles with a series of white Xs printed on them. In fact, the large interference found was almost exactly equal to that found for a traditional color/word condition. Grand (1968) used black words that were not color names and did not find a delay of color naming, whereas the same words when actually written in color did produce interference. This absence of interference with black backgrounds might suggest that contrast direction is critical with implications for the study of visual processing. Grand's negative findings, however, may instead reflect an inappropriate control condition in his study. Instead of having Ss name the color of colored rectangles without words or with nonsense syllables, his control condition consisted of nonsense syllables typed in colored ink. Although this was an appropriate control for the (typed) colored words, the area of the nonsense syllables would be very small compared to his colored rectangle stimuli. The difference in area could account for the similarity of latencies for naming colored rectangles with words in black and color naming with colored nonsense syllables.

One recent study (Dyer & Severance, in press) assessed the degree of interference that words would generate to color naming when black words were presented followed by nonword color patches. The main purpose was to develop a paradigm that would allow assessment of interference effects with stimulus dimensions that could not be combined with words. Such a paradigm would allow comparisons between dimensions of the degree that they are subject to Stroop interference. Significant delays in color naming of more than 40 msec occurred when incongruent color names in black preceded a series of colored Xs. The comparison condition was a series of black Vs that preceded the color stimulus.

Dyer (1972b) also presented black words and colored Xs to Ss, but instead of successive presentations, the word and color were symmetrically spaced on either side of a fixation point with the side of the word varying randomly from trial to trial. Exposures of 100 msec were too short to permit eye movements to relocate these stimuli on the retina. Ss were instructed to ignore the word and to name the color quickly. Times for naming colors when the opposite-side word denoted a color different from the color patch averaged nearly 50 msec longer than times for a condition where black Xs were paired with the color.

One new version of the Stroop test that might be referred to as a super-Stroop test because of its high interference was developed by Daniel (1969). Not only were words printed in incongruently colored ink, they were printed on colored backgrounds that were incongruent to the color name and different from the incongruent color of the word. The task was to name successively first the color of the background and then the color of the word, repeating this double color-naming task for each stimulus on the card. Times for this task were more than twice the time to name the colors of ink on the traditional interference card.

One presentation procedure that has generally failed to produce interference to color naming is an auditory presentation of the incongruent word stimuli in conjunction with nonword color patches. Thackray and Jones (1971) presented individual color patches with simultaneously spoken words as one of their conditions and found no delay in color naming compared to a condition without the auditory stimuli. Such auditory stimuli did not increase the interference to color naming even when the colors were incongruently colored color names. Simultaneous auditory presentations may not provide the critical timing (see Timing section below) of word and color processing that is necessary for Stroop interference to occur. To test this, Dyer and Severance[1] presented spoken incongruent color names at several intervals slightly prior to, during, and after presentation of a rectangular color patch. None of these conditions produced more than a trivial increase in the time to name colors over control conditions utilizing spoken neutral words. One implication of this finding (little or no interference from spoken words) is that reading is critical to the generation of naming interference. In the motor theory of speech perception (Liberman, Cooper, Harris, MacNeilage, & Studdert-Kennedy, 1967), an active response is claimed to be made by the perceiver's own vocal apparatus when he perceives a spoken word. The failure of spoken words to interfere with color naming suggests that this active response bears little similarity to an implicit reading response, if it exists at all.

A number of other variants of the Stroop test have used the conventional word-shaped color patch, with responses other than overt color naming. Tecce and Happ (1964) required card sorting on the basis of color with Stroop stimuli printed on the cards and found this condition to require much more time than was required to sort cards with simple rectangles of color printed on them. Pritchatt (1968) required a keypress response with keys corresponding to the colors. Stroop stimuli produced longer latencies for these responses than rectangular color patches, and the effect was greatest when the keys were labeled with words. With colored rectangles designating the keys, response times were only slightly longer for Stroop than for control stimuli. This finding suggests that the Tecce and Happ (1964) card-sorting task would have produced even more interference had they labeled their sorting boxes with words instead of colored rectangles. Treisman and Fearnley (1969) required the sorting into same and different piles of cards that carried two stimuli–two words, two colors, or a word and a color. Word-word and color-color matches were very fast with little or no interference, even when one of the words (word-word matching) or colors (color-color matching) was a Stroop stimulus, i.e., both a word and a color. When neither stimulus was a Stroop stimulus, word-color and color-word matching were slower than word-word and color-color matching. A further large delay in matching occurred when one of the stimuli was a Stroop stimulus. Dyer (1971d) used similar stimuli in word-color and color-word matching tasks with verbal same and different response times recorded individually. He found large delays in such responses when "irrelevant" incongruent word and color information was present. Hock and Egeth (1970) required judgments of whether or not a stimulus color matched a predetermined memory set of colors and found that such matching was disrupted by Stroop stimuli.

Differences in interference from Stroop stimuli in these different tasks aid our understanding of the Stroop phenomenon, and these results will be returned to in the final section of this paper. Since some of these tasks require additional perceptual, cognitive, or motor activity beyond the color naming of the traditional version of the Stroop test, they should be substituted for it with caution.

Asymmetries in Response to the Dual Aspects of the Stroop Stimulus

Since the word aspect of the Stroop stimulus strongly affects naming of the color, it is logical to assume that a similar interference might occur for the reading of the words as a result of the presence of colors. Stroop (1935) examined this possibility and found that reading words on the interference card (words in incongruent colors) was delayed by less than 6% relative to reading the words on a card with words written in black ink. This difference is sufficiently small that it could be only the result of the reduced legibility of the words on the interference card. The legibility reduction might result from reduced luminance contrast and perhaps from blurring of one color relative to another because of the chromatic aberration of the eye. However, Stroop provided evidence that real interference from the colors can be generated to word reading. He found that extensive practice on color naming caused a substantial increase in time for reading words on the interference card in a word-reading session that followed this color-naming practice. This effect declined very quickly, however, with reading times almost back to the levels that existed prior to color-naming practice on the second testing of word reading following that practice. This is quite unlike the consistently high interference from words to color naming that Stroop found throughout trials on 8 successive days of strictly color-naming trials. It must be remembered, however, that much other word-reading practice must have occurred for his undergraduate Ss.

Gumenik and Glass (1970) appear to have made a similar finding of interference to word reading from colors; however, their procedure did not control adequately for legibility differences that would be expected between their color-word card and a card with black words. Their rationale was that reducing the word legibility would weaken the reading response and would make this weakened response susceptible to interference from color naming. Besides the problem of a differential reduction of legibility that would be expected for the colored and black words, they also had all their Ss name colors just prior to word reading on the interference card. The above-mentioned results of Stroop (1935), showing the effect of color-naming practice on subsequent word reading on the interference card, indicate that this may have produced genuine interference but of a somewhat artifactual type. Dyer and Severance (1972) attempted to replicate the word-reading portions of the Gumenik and Glass (1970) study with inclusion of two additional controls: (1) a neutral-word-reading condition which would (presumably) not be subject to interference from color names and (2) a series of graded achromatic shades for the control-word-reading card instead of black words of constant high contrast. Apparently because of some unknown procedural difference, the word-reading conditions were not delayed to the extent that word reading was delayed in the Gumenik and Glass (1970) study. However, despite this failure to "weaken" the reading response to the same extent, colors did appear to interfere, since a significance increase of nearly 20% was noted in the time to read color words when they were presented in incongruent colors over the time to read the same words when they were printed in shades of gray. This was true despite a longer time required to read neutral words when they were in gray than when they were in color. It was true also despite a complete absence of color-naming trials prior to the word-reading conditions for the Ss. Thus, despite a poorly controlled study, the conclusions of Gumenik and Glass regarding word reading appear valid.

Another study (Uleman & Reeves, 1971) also claimed a small but significant amount of "reversed" Stroop interference. They compared scanning for a particular color name when the words on a card were in black and when they were in incongruent colors. Lund (1927) showed that scanning for words takes almost twice as long as scanning for a particular color. Uleman and Reeves hypothesized that this faster response to color than to words for this scanning task would lead to delays in scanning for a particular color name when competing colors were present on the interference card. They did find that scanning for a word was slower on the color-word card than on a card with black words, but the small difference could have reflected a legibility difference as much or more than interference, since their study lacks the same controls as that of the study of Gumenik and Glass (1970). However, Dalrymple-Alford and Azkoul (1972) report that Dalrymple-Alford, in an unpublished study, replicated the Uleman and Reeves result with materials that controlled for this legibility difference.

Generality of the Stroop Phenomenon

Closely related to the asymmetry in response to the two aspects of the Stroop stimulus is the question of the extent to which naming of other stimulus dimensions besides color is susceptible to interference from incongruent dimension names integrated with levels of the dimension. Smith and Borg (1964) were interested in producing a parallel form of the Stroop test which would allow retesting of Ss to increase the reliability of their serial scoring technique. They used achromatic shades (white, gray, and black) in incongruent combinations with their corresponding names. They found this version much less reliable than comparable color versions and generally unsuitable for their purposes. Dyer (1971a) used similar stimuli and found that interference (time for naming with incongruent word stimuli minus the time for naming with control stimuli) was about 40% less than that for a comparable color version of the test. However, scores on both versions correlated at a high level, indicating that despite the reduced interference both measured essentially the same thing.

White (1969) generated an interference paradigm analogous to the Stroop test by presenting one of the words *north, east, south,* and *west* within a square so that the word's position was incongruent to the position denoted by the word (e.g., the word *south* at the top of the square). The word positions for a series of such incongruent position-word stimuli were named, and the time for this naming was found to be 20% greater than the time to name the position of nonsense syllables. Although significant, this interference to position naming was much less than the 60% increase in color-naming time for incongruent color names over nonsense syllables found for the other groups in the experiment. Shor (1970) also explored an analog of the Stroop test in which spatial direction was combined with words denoting spatial directions. A series of arrows pointing up, down, right, or left, each with a word denoting one of the other directions written within it, were presented in the traditional Stroop format, i.e., cards of arrows with words written within them and a control card of arrows without such words. Time to name arrow directions was about 10% greater for the interference card than for the control card. This difference was significant, but it is much less than the 50%-100% increases found for the comparable color cards. In a later study, Shor (1971) compared a great many different tasks requiring responses to stimuli combining two aspects with at least one aspect normally a word, letter, or digit. Besides color and arrow direction, he used spatial position and a dimension of straightness-crookedness. Naming of all these dimensions was subject to interference, but only a small amount in comparison to that for the color stimuli.

In a similar paradigm to that of Shor (1970), Dyer (1972a) combined direction names with the dimension of movement direction by moving the words *up, down, right*, and *left* and also a series of four Xs in one of the directions up, down, right, or left on the oscilloscope face of a laboratory computer. Some facilitation of direction naming occurred for conditions where directions and words were combined congruently relative to the control (Xs) condition, but only a very small amount of interference was found for naming directions with the incongruent combinations. The interference effect was less than a fourth of that found for comparable color work with individual Stroop stimuli (Dyer, 1971c). The results were thus similar to Shor's (1970) finding of only low interference despite the closer integration of words and directions with the moving word display relative to his words written within arrows. Low interference prevailed even with a stationary preexposure of the word prior to its movement, which had been expected to increase interference (see Timing below).

The general failure of dimensions of arrow direction, spatial position, achromatic shade, movement direction, and form to provide a strong analog of the Stroop test suggests that processing of color information is in some way different from these other dimensions. Cramer (1967) found that it was more difficult for preschool children to name colors with the patches a mixture of nameable forms than it was to name forms with the forms printed in different nameable colors. The same stimulus plate was used for both tasks. If the form dominance that this task apparently illustrated in these children occurs throughout life, her result suggests that names are assigned with more difficulty to colors than to forms and perhaps to other dimensions as well. This may account for higher interference from irrelevant words to naming the dimension of color than to naming of other dimensions.

Windes (1968) perhaps first showed the potential of numerals to interfere with counting when the numerals were the counted objects. Many of the tasks reported by Shor (1971) also involved numerosity responses with the objects enumerated being a group of digits with the digits incongruent to their number. Numerosity does not intuitively appear classifiable as a stimulus dimension, but substantial interference to numerosity naming occurred in these tasks. Even more removed from a stimulus dimension are letters and numbers, the naming of which was considerably delayed (though not to the extent of naming colors) when the letters and numbers to be named were used to outline other letters and numbers. The stimulus dimension for these latter tasks might be regarded as form.

Morton (1969) also obtained data on a set of tasks largely involving enumeration, or perhaps more correctly subitizing, of various letter and digit stimuli. He found considerable interference from the irrelevant digits and letters. These results were conceptualized as equivalent or at least closely related to the Stroop test results. Morton also found interference from spoken digits in the enumeration of visually presented stimuli and also the enumeration of a series of distinct auditory events. This is in contrast to the previously discussed failure of spoken words to interfere with color naming (Thackray & Jones, 1971).

The fairly high interference found by Windes (1968), Morton (1969), and Shor (1971) for enumeration tasks suggests some comparability between color and numerosity dimensions. As presently conceptualized, these dimensions are quite unrelated if numerosity can be classified as a stimulus dimension at all. Sameness and differentness is another such "dimension," the naming of which Egeth, Blecker, and Kamlet (1969) showed can be interfered with to much the same extent as color and numerosity. They found that judging whether two rectangles of color were the same or different was greatly slowed when words spelling the words *same* and *different* were written on the rectangles.

One other failure to generate an analog of Stroop interference should be mentioned. Dyer and Mosko[2] required Ss to name voices with the single word voiced on a trial being the name of another speaker whose voice was used in the experiment (the control condition was a neutral word). This task reproduces in the auditory mode the conditions of the Stroop stimulus. Voice and irrelevant word are closely integrated, and both are completely auditory in nature. Times for naming voices saying incongruent or congruent voice names were almost identical to times for naming voices saying neutral word stimuli.

The failure of these conditions to change naming times for an auditory dimension appears to contrast with a recent study by Hamers and Lambert (1972). They looked at times to name the pitch (high or low) of a voice saying the words *high* or *low* and found over 100 msec difference between congruent and incongruent pitch-word combinations. Unfortunately, no control words were included to determine whether the effect was interference from incongruent combinations or facilitation of pitch naming with congruent combinations. One other difficulty for interpretation of their results was a 30% rate of errors for the incongruent pitch-word combinations, whereas only 6% of the congruent combinations were erroneously named. This difference indicates a strong tendency for the Ss to simply echo the irrelevant word aspect of the pitch-word stimulus. Such "correct" responding with congruent combinations might account for their faster response times. Further research is required to establish that auditory dimensions can provide a naming task with interference from irrelevant words which is analogous to the Stroop test. Such an effort would be highly worthwhile, since an auditory Stroop paradigm could be used to study speech recognition and other aspects of auditory perception.

Timing

Manipulation of the processing time for color relative to words can greatly reduce interference to color naming from irrelevant incongruent words and may also produce increases in such interference. In the portion of their study concerned with color naming, Gumenik and Glass (1970) showed that reducing the legibility of the incongruent names by a mask that minimally changed the visibility of the colors greatly reduced the interference of the incongruent color names to color naming. Dyer (1970) manipulated the background luminance of constant luminance color words and found high Stroop interference when, as a result of this manipulation, color naming was slow and word reading was fast. Interference was generally least for the conditions of minimal luminance contrast between the colored word and its white background. One problem of the study was that the background manipulation produced larger changes in color visibility despite constant color luminance than the changes in word visibility (color naming was delayed more than word reading). This concurrent variation of color and word processing rates allowed only a correlational analysis of this relationship of Stroop interference to these processing rates.

Klein (1964), in a little-discussed second experiment of his famous paper, had Ss read the word then name the color on the interference card and found that times for this double-response condition were only slightly greater than for a condition with color naming alone on this card. In addition, Ss reported that the task involved little of the strain that is characteristic of the performance on this interference card (e.g., Jensen & Rohwer, 1966). Taken together, the results of the Gumenik and Glass (1970), Dyer (1970), and Klein (1964) studies would predict that some optimal processing rate for colors relative to words would maximize interference to color naming from the incongruent words. Relatively fast color processing would be expected to produce the Gumenik and Glass (1970) condition of low interference. Fast word processing relative to color processing would also be expected to reduce interference because the reading response is "gotten out of the way" as it was for Klein's (1964) dual-response condition. To test this prediction, Dyer (1971c) used an individual stimulus technique and preexposed words in black for various intervals prior to coloration, presumably advancing word processing relative to color processing. Color-naming latencies were measured from the time of coloration of the black word. These latencies increased slightly then decreased sharply as black word preexposures varied from 0 to 500 msec. Maximum interference occurred at 40 msec preexposure with a sharp drop in interference for preexposures greater than 60 msec. Some interference to color naming occurred even with the longest preexposures. Congruent combinations of words and colors were included to prevent the word from serving as a cue to reduce the response set.

The importance of relative processing rates of words and colors suggested an explanation of the reduced interference found by Dyer (1971a) for achromatic shades compared to a chromatic version of the Stroop test. Control achromatic shade rectangles were named slightly faster than control colored rectangles, and word processing times were approximately equal for the two conditions. It was thus assumed that the Gumenik and Glass (1970) low-interference condition of fast dimension processing relative to word processing already existed not as a result of slowing word processing, but as a result of inherently faster processing of achromatic shades. Given the apparent success of this explanation, it was assumed to also account for the even lower interference conditions found for direction naming by Shor (1970) and the similar results of pilot work for a study (Dyer, 1972a) with moving word stimuli on the computer oscilloscope. It was assumed that the dimension of direction was processed even more rapidly than achromatic shade and that this was the basis of the low interference for direction naming. A similar explanation would probably apply to all noncolor dimensions producing low interference. To test this explanation, an analogous experiment to the study of color naming with black preexposures (Dyer, 1971c) was conducted. Word stimuli were presented for various intervals prior to movement on the center of the oscilloscope face, then moved in one of four directions. It was assumed that some stationary preexposure of a particular length would maximize interference and, in fact, bring this interference to the levels obtained in experiments with color. The results of two experiments (Dyer, 1972a) indicated that, although stationary preexposures of the word for 200 msec or more reduced the small amount of interference to even lower levels, not one of eight preexposures between 0 and 200 msec caused any appreciable increase in interference to direction naming. Ironically, this apparent disconfirmation of the hypothesis that the processing rate of a dimension relative to words is the critical feature is itself contradicted by data from the same study that indicated that interference to direction naming was proportional to the amount of time it took to name a particular direction. Direction naming in control conditions was fastest for up, followed by down, left, and then right. Correspondingly, interference to direction naming was least for up, followed by down, left, and then right. Some validity to the hypothesis of a correlation of high interference with fast word processing relative to dimension processing thus may still exist, although stationary preexposures of the word do not produce the "fast word processing relative to dimension processing." The result argues that the study of color naming with black preexposures (Dyer, 1971c) may not be a true study of the effects of different relative word and color processing rates either.

Sequence Effects

Although the individual stimulus presentation method does provide important benefits for the analysis of Stroop processes and allows applications of it for study of other variables, the amount of interference is considerably higher for the more traditional version where total naming time is obtained for a card of incongruently colored color words. Response times for the incongruent name condition in individual stimulus versions are usually less than 25% greater than for control conditions, whereas interference card times in traditional versions are usually from 50% to 100% longer than color-naming times for the card of control patches. At least two factors appear to account for the greater times with the cards of multiple stimuli. One is a delay of responding to a color stimulus produced by response competition due to the presence of other color stimuli. The other is the effect of suppression of the irrelevant word response and color naming for one Stroop stimulus on the suppression and naming responses to the next stimulus. Sichel and Chandler (1969) found that color naming for the first of two stimuli took over 200 msec longer than color naming for a single Stroop stimulus. They attributed this increased response latency to competing response tendencies generated by the presence of the second Stroop stimulus. Another possible explanation is that Ss adopted a strategy of processing both stimuli prior to responding to either, since they were instructed to name both. If they had been instructed to respond to only the first of the two stimuli, they might not have shown this delay. Some support for this comes from the fact that the relationship of the second stimulus characteristics to those of the first was a critical factor in the amount of time required to name the first stimulus. In fact, they later discussed this delay of naming with two stimuli as reflecting the effects of responses to the first stimulus—both suppression of the irrelevant response to the word and making the appropriate response to the color—on responding to the second of the stimuli. This would seem to imply a fairly high level of processing of both stimuli prior to the response to the first color stimulus.

The most protracted color-naming response in the Sichel and Chandler (1969) study occurred for a pair of stimuli in which the color of the first corresponded to the word of the second and conversely the word of the first corresponded to the color of the second (e.g., the word *red* in green followed by the word *green* in red). For such a combination, the first suppressed response to the irrelevant aspect becomes the appropriate response to the second and the recently completed response is the response that must be suppressed on the next stimulus. Because of the high level of interference found for this "suppress-say/say-suppress" combination, a useful version of the Stroop test was created by these authors which was made up largely of such pairs of stimuli.

Dalrymple-Alford and Budayr (1966) also explored the effects of particular sequences of Stroop stimuli on color-naming times. Traditional versions of the Stroop test such as the version recommended by Jensen and Rohwer (1966) present the series of stimuli on the card subject to the constraints that succeeding words and succeeding colors differ. Dalrymple-Alford and Budayr studied the effects of three different sequential conditions. In one, the colors differed on succeeding stimuli and, in addition, the color never corresponded to that denoted by the previous irrelevant word. For a "say-suppress" condition, the irrelevant word always corresponded (after the first stimulus) to the preceding color. For a "suppress-say" condition, the color always corresponded to the preceding irrelevant word. Unlike the latter two conditions, the first does not involve either saying a previously suppressed word or suppressing a previously said word. The "say-suppress" condition did not differ from the condition where succeeding stimuli bore no relationship between irrelevant words and colors. On the other hand, the "suppress-say" condition required 20% more time for responding than either of these two.

A combination condition, i.e., suppress-say/say-suppress, such as that used in the stimulus pairs by Sichel and Chandler (1969) cannot effectively be extended in a pure form for more than two stimuli, since there would only be two stimuli which would alternate. In this respect, even the Dalrymple-Alford and Budayr conditions are somewhat suspect. On cards utilizing only the "say-suppress" condition or the "suppress-say" condition, the S can respond correctly to the colors by reading the words. This reading response is correct for the preceding color stimulus in the "say-suppress" condition and for the following color stimulus in the "suppress-say" condition. However, no indication of Ss' adopting such a strategy occurred for the Dalrymple-Alford and Budayr study.

USE OF THE STROOP PHENOMENON TO STUDY OTHER PROBLEMS

The studies and their findings described in this section of the review were primarily concerned with other psychological processes and used the Stroop phenomenon as a tool to explore these processes. Much information about the Stroop phenomenon itself is available in these results, however, and many of them could as easily have been included in the earlier section. The present section is demarcated from the first in an attempt to orient the reader to the rich potential that the Stroop phenomenon offers for studying other processes.

Interference to Color Naming as an Index of Word Meaning

Perhaps the most important Stroop paper since Stroop's original work was a study of the late G. S. Klein (1964). Using a traditional format of cards of color patches, he illustrated that interference to color naming appeared for words other than incongruent color names. His six different word types consisted of nonsense syllables, rare words, common words, words such as *grass* and *sky* that "implicate the colors in their meaning," color names from a set of colors different than those being named, and the traditional incongruent color-name plate. The percentage increase in naming times for these different word types over a control condition where the color patches were asterisks was 12% for nonsense syllables, 17% for rare words, 27% for common words, 35% for color-related words, 41% for distant color names, and 85% for the traditional close color-name condition. These results clearly indicate the potential of color naming of word-shaped color patches to provide an objective indication of differences in the meaning of words, even though "meaning" is confounded with color-relatedness. Both the differences illustrated to exist between classes of words unrelated to color and the differences between classes of words which are color-related have general importance for theories of word meaning.

Scheibe, Shaver, and Carrier (1967), in a very similar study to Klein's, showed that interference to color naming was directly related to the frequency with which the words used to interfere were associated with the colors to be named. It is interesting that in both studies the close color-name condition provides over twice the interference of the distant color-name condition. Hochman manipulated the rate at which individual colored word stimuli from different word classes were presented and recorded as the dependent variable, the number of erroneous responses in adults (1967) and young Ss (1969). In both studies, he found that when the words were incongruent names, they produced the most errors with the error rate dropping systematically as the words changed through the Klein categories to nonsense syllables. More recently, Fox, Shor, and Steinman (1971) showed that Klein's basic finding also applied to other dimensions besides color. They found that spatial direction and numerosity naming were delayed as the semantic aspects of the stimuli ranged from incongruent names to nonsense words and figures.

Dalrymple-Alford (1972a) used an individual stimulus procedure and also showed that words related to colors delayed color naming more than unrelated words. A unique aspect of this study was the inclusion of color-related words with the related color *congruent* to the word's color. Color naming for these stimuli was significantly faster than for unrelated words. In another study, Dalrymple-Alford (1972b) showed that sound similarity between words and color names matches semantic similarity in the production of delays of color naming. Words with similar first sounds (e.g., *run, blot, grown*) or similar last sounds (e.g., *bed, true, queen*) to the names of the colors produced more interference than unrelated words when used as Stroop stimuli.

Bakan and Alperson (1967) investigated both meaningfulness and pronounceability and claimed that both were important factors directly related to the amount of interference that word stimuli generated for color naming. Their results were unambiguous for the meaningfulness dimension, but due to confounding of meaningfulness with pronounceability, the role of pronounceability is somewhat in question.

Ellison and Lambert (1968) used the Stroop phenomenon to study semantic or verbal satiation (Kanungo, 1967) in which word meaning is decreased or even eliminated by continuous repetition or viewing of a word. Ellison and Lambert hypothesized that if the color names were subjected to the satiation procedure, they would produce less interference on a subsequent administration of the Stroop test. They found a very small reduction of interference following satiation of color names relative to a condition with satiation of other words. The effect was stronger for the first half of the card of colored color names. This suggests that a study of this type using the individual stimulus procedure might more adequately assess the effects of semantic satiation on color naming. In fact, semantic satiation may be one possible interpretation of the reduced interference in the study in which words were preexposed in a neutral color prior to coloration (Dyer, 1971c).

Interlingual vs Intralingual Interference in the Stroop Test

Dyer (1971b) showed that English-speaking monolinguals showed interference to a form of the Stroop test using translation equivalents of incongruent color names as interfering stimuli with the amount of interference directly related to the similarity of these interfering words to their English equivalents. Preston and Lambert (1969) and Dyer (1971b) both showed that for bilinguals, the condition where the interfering words were in one of the bilingual's languages and the color naming was to be done with the other language produced a great amount of interference, although significantly less than when color naming and interfering words were both in the same language. The high interlingual interference levels support Dalrymple-Alford's (1968) position that bilinguals do not "turn off" or even greatly attenuate one language while speaking in the other. However, the significantly smaller interference in the interlingual condition compared to the intralingual condition does appear to argue for some separation between languages for bilinguals other than the differences between individual words which exist as well for different words of the same language.

Assessment of the Contents and Structure of Memory

A very interesting application of the Stroop task was recently made by Warren (1972). He determined the strength of word representations in memory by measuring the amount of interference such words generated to color naming when they were used as color patches. He used words that were unrelated to color and introduced the word to memory at various periods prior to its use in the color-naming task. Presentation of the words was auditory and was found to greatly increase the word's interference to color naming when it was later written in colored ink. Such introduction also increased the interference potential of the category name to which the word belonged. Warren also made important initial steps to assess changes over time in the strength of these word representations in memory. Although time and trials were confounded, the strength of the word in memory was shown to decline linearly with 1-31 sec of storage prior to its use as a Stroop stimulus.

Subliminal Perception

A great deal of controversy has been generated regarding whether word stimuli can be responded to although they are exposed so briefly that they cannot be recognized. Following the format of the study (Dyer & Severance, in press) that produced interference to color naming with black words followed by colors, Severance and Dyer (1972) presented black words for durations that were too short for recognition and followed this with 50 msec supraliminal colored Xs. Times to name the colors did not differ as a function of whether the subliminal word stimulus was an incongruent color name, congruent color name, or a series of Vs. The study with supraliminal presentations of the words had produced over 40 msec of delay between the incongruent and control conditions, and facilitation of 10-20 msec occurred for color naming in the congruent condition. This was in marked contrast to the subliminal study where a nearly total absence of differences between any important conditions occurred.

Hemispheric Processing Differences

Milner (1971) has discussed processing advantages that accrue to particular dimensions when they are localized to one hemisphere instead of the other. Not only does there exist the well-known superiority of the dominant hemisphere for processing verbal materials, but the nondominant hemisphere processes certain nonverbal dimensions better than the dominant hemisphere. If color were one such dimension that was better handled by the nondominant hemisphere, one would predict that stimulating this hemisphere alone with a Stroop stimulus would reduce the interference. Presumably, the color would be processed more rapidly than the word by this hemisphere and a strong representation of the color would be transmitted back to the dominant hemisphere for naming, along with a weak or delayed representation of the word. On the other hand, when the Stroop stimulus was sent only to the dominant hemisphere, the strong representation of the irrelevant word would be expected to interfere greatly with the color representation which might require transmission across the corpus callosum to "its" hemisphere and back. Even if color was not a dimension favored by the nondominant hemisphere, one might predict that the more "robust" representation of the irrelevant word when the Stroop stimulus was transmitted to the dominant hemisphere would result in more interference for this condition.

To test these hypotheses, both predicting more interference from presentations of Stroop and control stimuli to the right visual field than to the left with right-handed Ss, Dyer and Harker[3] used vertically written stimuli presented briefly on one or the other side of the visual field. Stimuli were written vertically to control for peripheral location, and the brief exposure was to prevent eye movements from centering them. Although considerable interference occurred in each of two studies which differed in the peripheral location of the stimuli (45 min vs 2 deg), no difference in response times or in interference appeared between the different hemiretinal presentations in either study.

Some promise for the existence of a Stroop paradigm that will differentiate hemispheric function was shown by the presentation procedure described earlier (Dyer, 1972b) in which separate words in black and colored rectangles were presented bilaterally with the side of the color (and word) varied randomly from trial to trial. This procedure showed considerable interference, but for the color red this interference was much greater when the word was on the right and the color on the left. To some extent, this was also true for the color blue, but it was not true for green in the first experiment with three colors or for green and yellow in the second experiment with four colors. The result for red appeared with considerable strength in each of the experiments. Further research is under way to determine if this paradigm can reliably indicate functional differences between hemispheres.

PROPOSED MECHANISMS AND LOCI FOR THE STROOP PHENOMENON

The Stroop phenomenon has been "explained" by many different investigators over the past years. This continuing tendency to provide new explanations and to repeat old ones suggests that the various explanations have been somewhat less than adequate. Most of these explanations have considered the phenomenon in terms of response competition with a stronger reading response to the irrelevant word aspect of the stimulus dominating and delaying the color-naming response. However, these similar explanations often differ in their accounts of the differing strengths of reading and naming responses. Probably the most notable exception to the response-conflict explanation was that of Hock and Egeth (1970), who claimed the interference resulted from different color encoding for incongruently colored color words than for control color stimuli. Dalrymple-Alford and Azkoul (1972) have recently shown the inappropriateness of this explanation. Their arguments will be reiterated in this section, and further discussion of the inappropriate conclusions of the Hock and Egeth (1970) work will be presented. Following this, the various versions of the response-conflict explanation will be discussed, including one (Treisman & Fearnley, 1969) which the authors deny fits this category. Finally, a new explanation will be presented involving both response competition and a failure of selective attention. Prior to these discussions, however, a series of studies utilizing colored incongruent color names as stimuli are described. These studies generally involve responses to the color aspect of the stimuli other than naming or categorizing on the basis of names and show little or no interference from the irrelevant word aspect. These studies provide strong evidence for the importance of response conflict in the Stroop phenomenon.

Tasks Where Irrelevant Words are Actually Irrelevant

Derks and Calder (1969) required Ss to count the number of times a particular color appeared on a card of color patches. No differences in counting times appeared between a card of color patches that were Xs and a card where the patches were incongruent color names. Egeth, Blecker, and Kamlet (1969) required their Ss to indicate whether the colors of a pair of color patches were the same or different and found no difference between conditions where the pairs of patches were embossed with white Xs or with white incongruent color names. Pritchatt (1968) found that keypress responses to incongruently colored color names showed very little interference from the irrelevant words when the keys were labeled with colors. A similar unpublished study by

Azkoul, reported by Dalrymple-Alford and Azkoul (1972), showed that with repeated practice, Pritchatt's Ss would probably have eliminated the small amount of interference found with his keypress task. Treisman and Fearnley (1969) required sorting of cards with two color patches on the basis of whether the two colors were the same or different and found that this was extremely fast despite the fact that one color patch was a Stroop stimulus.

None of the above tasks required overt color naming, but under certain conditions, even a task that requires naming will not be interfered with by irrelevant words. Derks and Calder (1969), in a second study, required the S to name a single target color as well as to count it and showed this too produced no difference in response time between Xs and Stroop stimuli. Uleman and Reeves (1971) found that times to scan for a single color on a card of Stroop stimuli, both checking and naming it upon detection, did not differ from times for such scanning, checking, and naming with control color stimuli. It appears in all these studies that the S is attending to "the rapidly formed but nondurable stimulus representations formed by the sensing stage of perceptual processing [Hock & Egeth, 1970, p. 300]." Even when naming was involved, the single naming response for the single target stimulus eliminated any need for selection of such a response and could probably be produced automatically upon reception of a "sensing-stage" cue.

The Case for a Perceptual Encoding Explanation

Hock and Egeth (1970) used the Sternberg (1969) paradigm in which reaction time is determined for classification of stimuli as members or nonmembers of a previously learned target set to study the encoding and classification of colors presented as verbs, incongruent color names, or a series of Xs. The memory sets were one, two, or three colors defined by name prior to presentation of the series of color stimuli. Sternberg (1969) has shown that variables which affect the encoding of the stimuli lead to differences in reaction time that are constant for different memory set sizes. On the other hand, variables which affect the more central comparisons with the memory set produce curves of different slopes when reaction time data is plotted against memory set size. As Dalrymple-Alford and Azkoul (1972) point out, since the memory set is probably color names, the encoding of the stimuli for making the memory match would involve covert generation of the names of these color stimuli. Because of this, response competition effects from irrelevant words which delay this encoding would not be expected to have any different effect depending on memory set size and no interaction of Type of Verbal Material by Size of Target Set would be expected. Dalrymple-Alford and Azkoul's arguments indicate that it is inappropriate for Hock and Egeth (1970) to conclude that differences between word types represent differences in speed of perceptual encoding of the color component for the three types of stimuli unless they extend this encoding to include covert naming of the color stimuli. Hock and Egeth do distinguish between low-level color encoding which is not delayed by irrelevant words combined with the stimuli and "high-level" encoding which is so delayed. They thus appear to have provided a valid and useful distinction but do not admit that the characteristic of high-level encoding is that covert or overt word responses are generated, as Dalrymple-Alford and Azkoul have convincingly argued.

In their conclusion that type of verbal material does not interact with size of the memory set, Hock and Egeth (1970) also fall into an error that Sternberg (1971) has warned against—using statistical tests designed to reject the hypothesis of no interaction as a basis for accepting the hypothesis that there is no interaction. The error is to assert a lack of interaction between variables when the insignificance may merely reflect imprecision in the experiment that prevented achievement of significance. Their Type of Verbal Material by Size of the Target Set interaction produced an F of 1.58, which, with $df = 4$ and 60, would occur only one in five times by chance. Their probable inappropriate rejection of the existence of this interaction does not bear on the verbal conflict that accounts for longer response latencies with incongruently colored color words, but it does mask what may be an even more interesting finding. The memory set may be qualitatively different when it is of Size 1 than when it is larger. It is also possible that the memory set is qualitatively different at different times in the sequence of memory matches. The absence of interference from irrelevant words in scanning, matching, and counting of colors implies that a sensory representation can be held at least as long as it takes to find successive stimuli of the target color. Even if it is not possible to generate such a sensory memory from a name, following presentation of a stimulus from the positive set, it would be expected that this would be available for at least the next comparison. The faster times found by Hock and Egeth (1970) with the Size 1 memory set than with larger set sizes, for incongruent in comparison to control stimuli, could well reflect savings resulting from memory matches of such a sensory nature for Size 1 memory sets.

The failure of the attempt by Hock and Egeth to show that sensory or perceptual encoding of colors can be interfered with by written words does not necessarily indicate that such an effect is not possible. In fact, a study by Tecce and Dimartino (1965) might be taken as evidence that words can affect perception of colors. Their data appear to indicate that words spoken at the time that brief color flashes occurred facilitated recognition of the color when they were the same as the color and delayed their recognition when they were incongruent to the color. Recently, Dyer and Behar[4] conducted a study in which color names and control Vs were exposed in black for 50 msec and then one of three colors was flashed in the black area for 0, 2, 5, 10, or 20 msec. The S was required to identify the color or to guess it if unable to recognize it. The 0-msec exposures were included to obtain a measure of guessing rate for the different word conditions. In the "0" condition, it was found that the control Vs produced a hit rate of 33%, exactly in line with what would be expected for three colors. When word stimuli were used in the "0" condition, Ss guessed the color corresponding to the word 42% of the time. This meant that only 58% of the time did they guess a color different from that denoted by the word. Approximately the same proportion of color responses congruent to the word were found for the very brief 2-msec exposures of the color. It was probably this influence of the word on guessing that accounted for what might instead be interpreted as a facilitation of recognition with congruent combinations of words and colors and a delay of recognition with incongruent combinations. Longer color flashes which definitely did allow some recognition showed no consistent differential improvement or delay as a result of their combination with congruent and incongruent words. In light of this result, the claim of Tecce and Dimartino (1965) for an effect of spoken words on recognition can be largely discounted.

The 50-msec word exposure prior to color flash in the Dyer and Behar study[4] would probably not be sufficiently ahead of the color to generate activity corresponding to the word that could influence encoding of color stimuli. This is because such color encoding appears to be faster at sensory stages than is the encoding of words (e.g., Uleman & Reeves, 1971). The 50-msec word exposure was selected since 40 and 60 msec of preexposure of black words had maximized interference in the Dyer (1971c) study of the effect of black word preexposure on color naming. The Dyer and Behar study[4] thus does not prove that words *cannot* affect color encoding as determined by recognition, only that it does not do it in normal presentations of Stroop stimuli and even when the word is presented slightly before the color. This factor thus cannot account for any part of the delay in color naming that occurs when words are presented simultaneously with colors or slightly before.

Response Conflict Explanations

It is almost ironic that the counting, scanning, and matching tasks which were described earlier in this section are faster for a target color than for a target word (e.g., Uleman & Reeves, 1971), whereas a naming response occurs much more quickly to a written word than to a color patch. This faster reading than naming applies to other dimensions than color and is classically illustrated in Fraisse's (1969) finding that reading an "O" when it was presented as one of four possible letters was 166 msec faster than naming the identical stimulus as a "circle" when it was presented as one of four possible geometric forms. Fraisse (1969) concluded after a series of experiments that neither differential practice on reading compared to naming nor stimulus discriminability could account for the basically faster reading than naming. Another aspect of this basic difference is shown in the work of Morin, Konick, Troxell, and McPherson (1965) and of Gholson and Hohle (1968), who showed that letter and word reading were relatively independent of the size of the set of letters or words to be read, whereas the time to name colors, faces, animals, and geometric forms all increased greatly as the size of the stimulus set increased.

Almost every investigator of the color-word phenomenon since Stroop (1935) has viewed the further increase in color-naming time when the patches are words as a direct result of this faster assignment of spoken words to written word stimuli than to colors and the resulting conflict between this faster response to the irrelevant word aspect of the stimulus and the response to the relevant color aspect of it. Some have speculated further about the difference between naming and reading, and a few have been concerned with the nature of the response conflict and its resolution. At least one investigator (Treisman, 1969) has discussed the question of why selective attention, which can gate the irrelevant word when the task is one of counting, scanning, and matching colors, fails to gate such irrelevant inputs during color naming.

Stroop (1935) suggested that the faster naming of words than of colors resulted from the fact that a variety of responses are learned to a specific color besides its name, whereas only the name response is learned to the written color name. Such an explanation does not seem particularly satisfactory, and to the author's knowledge no one has shown that reading responses are delayed as a result of learning other nonreading responses to a word stimulus. This would seem to be an appropriate test of this hypothesis. Gholson and Hohle (1968), however, found this explanation to be the only one available which could provide even a somewhat satisfactory account for their findings of differential increases in time for naming of colors and forms with increased stimulus set size relative to naming of words. Schiller (1966) rejected the differential practice explanation of reading/naming differences, but his alternative explanation—that the individual letters, word length, etc., constituted a much more redundant stimulus than a color patch that differed only on the dimension of hue—does not appear to square with the faster processing of these color patches when the task is counting, scanning, or matching.

Although Treisman and Fearnley (1969) deny that their explanation of the Stroop phenomenon is a response-conflict explanation, it would appear that they have reemphasized and provided a partial explanation of the fact that word responses are produced more rapidly in response to written word stimuli than to color stimuli. Their experiment showed that judgments of same and different (in a card-sorting task) were much faster for pairs of stimuli that were two words or two colors than for pairs of stimuli that were a color and a color name. Large further delays in "cross-attribute" matching resulted when one of the stimuli was combined with an irrelevant stimulus from the other dimension. These different matching tasks produced sorting-time differences that closely parallel the differences found between word reading, control color naming, and color naming with interference from irrelevant words. On the basis of this, they reach the conclusion that reading words is similar to judging whether two-word stimuli are the same or different and that naming a color is like determining the same thing with a word stimulus and a color stimulus. This implies that stimuli and responses vary in their degree of similarity to each other and, specifically, that a written word is more similar than an object to the spoken word that names both. A possible basis for greater similarity between written words and their spoken names than between objects and their spoken names could be that the perceptual event associated with viewing a word includes an auditory component, while perception of the object does not include this auditory activity. Such auditory activity could provide a stronger connection between the word and naming response, since it would be similar to the sensory feedback produced by the naming response. Greenwald (1970) has recently provided considerable evidence for a direct relation between the degree of similarity of a stimulus to the feedback from the response and speed of responding. For example, he has shown that a word can be spoken faster when it is a response to the same auditorily presented word than when it is read. The auditory stimulus is much more similar than the printed word to the sensory feedback from the naming response. A parallel closer relationship of the stimulus to the "feedback from the naming response" for the written word than for the object may also exist and account for faster reading than naming.

Interference was found by Treisman and Fearnley (1969) in the cross-attribute matching task regardless of whether the irrelevant aspect was a word or color. When the relevant color is combined with an irrelevant word, this would appear to be interference from covert reading of the word to the covert naming of the relevant color (this is required for the judgment). Except for the fact that the naming is not overt, this is similar to the response-conflict processes that investigators from Stroop (1935) to Dalrymple-Alford and Azkoul (1972) have called on to explain the Stroop phenomenon itself. When the relevant word is combined with an irrelevant color, on the other hand, it could be transformation of the relevant word to a color code that is disrupted by the presence of the irrelevant color. If this were true, then the Stroop phenomenon might be thought of as a specific case of a general interference with stimulus transformation that occurs when the stimulus to be transformed is in the presence of an irrelevant stimulus that is already close to the form to which the relevant stimulus will be transformed. This might apply only to transformations between words and things or might be even more general.

An extension of the Treisman and Fearnley (1969) experiment by Dyer (1971d) analyzed latencies of individual same and different responses when the pair of stimuli was a word and a color. Same responses were equally delayed when the irrelevant stimulus was a word or a color. Different judgments were slower when the irrelevant stimulus was a word than when it was a color. Largely for this reason, it was concluded that for the different responses, a word code was used for the central comparison. When the irrelevant stimulus was a color, it would not be in the form of the central comparison and hence would not particularly interfere with the match between the relevant word and the transformed uncombined relevant color. Morton and Chambers[5] have produced further data indicating more delay for card sorting in the "cross-attribute" matching task when the irrelevant value is a word than when it is a color, although it appears that they interpret this result somewhat differently. It may be that the form of the central comparison depends on the form of the uncombined stimulus and also the equivalence or nonequivalence of the word and the color, i.e., whether the response is same or different.

Perhaps the most elaborate response-conflict model of interference in Stroop-like tasks has been provided by Morton (1969). Interference to card sorting on enumeration tasks was seen to occur from an irrelevant symbol which readily generates a naming response that occupies a serial response buffer. This prevents the proper naming response used for sorting from occupying the buffer as soon as it would without the irrelevant stimulus present. It is a very general model that allows for auditory as well as visual interference to both enumeration of visual objects and enumeration of auditory events. However, Morton's general conclusions from a series of experiments are much the same as those presented here. The interference is not seen to occur prior to availability of the symbol name, and the interference is a form of response competition. It is of interest that auditory interference to color naming and voice naming was not found by Thackray and Jones (1971) and Dyer and Mosko.[2] This suggests that Morton's model may not apply to the Stroop phenomenon as well as it does to his enumeration tasks. Morton's model will be returned to in a subsequent analysis of response competition processes.

The Role of Selective Attention in the Stroop Phenomenon

Treisman and Fearnley's (1969) study of within- and cross-attribute matching illustrated that it was *not* a differential ability to focus on words and gate colors compared to focusing on colors and gating of words that produced the Stroop phenomenon, since color-color matches were as fast as word-word matches and were not disrupted by the presence of irrelevant words. However, largely on the basis of the Stroop phenomenon, Treisman (1969) concluded that it was difficult, and perhaps impossible, to focus on either the word or color analyzer with gating of the input from the other analyzer. It is thus possible to conceive of the response competition in the Stroop task as occurring because of this failure of selective attention to focus on colors and gate word input. The fact that fast counting, matching, and scanning for colors do not result in interference from irrelevant words may only illustrate that attention must be directed to both aspects of the stimulus *long* enough for this parallel processing of relevant and irrelevant aspects to proceed to a level where interference will occur. However, it may be more than time that is involved; attention may have to be directed to the level (perhaps auditory) at which name responses to the sensory representations emerge.

The generality of Treisman's (1969) conclusion that focusing on one analyzer is difficult or impossible is called into question by the failure of many dimensions to show much naming interference when combined with irrelevant words (White, 1969; Dyer, 1971a, 1972a; Shor, 1970, 1971). It could be that the color analyzer is a special type on which attention cannot be focused, whereas achromatic shades, movement direction, spatial position, etc., do allow at least some focusing with consequent attenuation of the irrelevant words.

Of possible relevance to the question of selective attention and the Stroop phenomenon is the work of Houston and T. Jones (1967) and Houston (1969). Although Thackray and K. Jones (1971) found that spoken names did not affect either control color naming or interference color naming, these other studies have demonstrated a very interesting interaction relating to the effect on color naming of continuous sounds such as trains, gibberish, and electronic music. These sounds delay color naming in the condition without interference but actually speed color naming in the condition with interference from irrelevant words. Unlike spoken color names, the Houston sounds may reliably elicit name responses and as such may serve to interfere with color naming much as the irrelevant written words do. The fact that such stimuli are continually present and naming responses stimulated by them are continually being rejected apparently aids the S in rejecting the irrelevant words on the interference card as well. This is basically the explanation that Houston and T. Jones put forth for their data. This result appears to argue for some perceptual strengthening of color or inhibition of other inputs.

WHAT IS THE BASIS FOR RESPONSE COMPETITION?

The most elaborate response-conflict explanation was provided by Klein (1964), who discussed a need for restimulation by the color aspect of the colored color word to overcome the irrelevant response to the word and to allow generation of the proper response to the color. In Klein's position, the need for restimulation occurred because it was considered easier to attend to the word and ignore the color than the converse, an attentional hypothesis that Treisman and Fearnley (1969) have well discounted. Still Klein's restimulation position without the emphasis on attention may have validity. Klein found that reading the word prior to color naming reduced the S's interference effects greatly, and, in fact, the double response required only a little more time than naming colors alone on the interference card. Similarly, black preexposures of the word prior to coloration (Dyer, 1971c) greatly reduced interference from the irrelevant word when the preexposures were longer than 100 msec. Thus, some relevance of Klein's restimulation hypothesis may exist such that, with traditional simultaneous presentation of both the word and color, a person waits for the word activity to "die down" and then processes the color to naming. Attractive as this "explanation" of the delay is, the restimulation by the color must be possible from a nonerasable iconic image of the stimulus because Dyer and Kuehne (1972) showed that very brief presentations of single Stroop stimuli as short as 25 msec produced "normal" interference to color naming in comparison to similar short presentations of control stimuli. This was true both with and without an erasure stimulus that followed the brief Stroop stimulus. Without this erasure stimulus, interference and response times were almost identical for presentations of 25, 50, 100, 200, and 500 msec. With the mask, only when it immediately followed the 25-msec exposure was there a change in interference (a nonsignificant reduction).

Perhaps the best present explanation for response competition includes both Treisman's (1969) claim of an inability to focus on either the color or word analyzers and Morton's (1969) assumption of a single response channel. The faster reading response tends to occupy the channel before the color-naming response can do so. The word response activity, however, has a very short time course as shown by the Dyer (1971c) black preexposure study, and this frees the response channel for the appropriate color-naming response. This correct response has already been selected or else can be generated from very brief "masked" stimuli (Dyer & Kuehne, 1972). Associative closeness of the irrelevant words to the response words [Morton's (1969) priming hypothesis] may account for the differential ability of irrelevant words from different classes to occupy the single response channel.

Of course, many things are absent in this explanation, including how the identity of the correct aspect and/or incorrect aspect for response is maintained. A possible solution could be derived from the Dalrymple-Alford and Budayr (1966) study of sequential effects with the first available (reading) response being suppressed and the second response being amplified. However, the facilitation of color naming by congruent combinations which occurs with immediate feedback of response times (Dyer, 1971c; Dyer & Kuehne, 1972) indicates that the tagging of responses to stimuli must be different than a temporal process of suppression followed by amplification.

Of all the gaps in our explanation of the Stroop phenomenon, the most critical unanswered question is probably that asked by Fraisse (1969): "Why is the time for reading faster than the time for naming?" The search for this answer and for the answers to other questions about the Stroop phenomenon appears to be highly worthwhile. The answers, when obtained, will apply to many other important questions about the attentional, reading, and naming processes which are not specific to this phenomenon but which constitute the basic fabric of cognitive behavior.

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NOTES

1. Dyer, F. N., & Severance, L. J. Failure of spoken incongruent names to delay color naming. In preparation.
2. Dyer, F. N., & Mosko, J. D. Failure of spoken incongruent speaker names to interfere with voice naming. In preparation.
3. Dyer, F. N., & Harker, G. S. Stroop interference with stimulus presentations to the right and left hemispheres. In preparation.
4. Dyer, F. N., & Behar, I. Absence of effects on color recognition of congruent and incongruent color name stimuli. In preparation.
5. Morton, J. Personal communication.

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