The effects of amount of information in the Stroop color word test

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The processing time of the relevant (color) and irrelevant (word) stimulus dimensions in a Stroop color word test were each varied by manipulating the amount of information in the color and word sets from which the stimuli were obtained. Interference in the Stroop task was found to increase with increases in relevant and irrelevant stimulus information. It was concluded that the findings of increased interference with increases in both word and color processing time supported a perceptual conflict interpretation of Stroop task interference.

A frequently used experimental paradigm for the study of selective attention is the Stroop task (Stroop, 1935). In this task, words that are the names of colors are printed in colored ink, for example the word "RED" printed in blue ink. The subject is required to report only the color of the ink. When the color of the ink differs from the word, the subject's response time is longer and his accuracy less than under control conditions when he seeks the ink color without the word. There have been two major interpretations of the locus of interference in the Stroop task: (1) a perceptual conflict hypothesis according to which interference occurs during stimulus encoding, and (2) a response competition hypothesis suggesting conflict localized at the point of response initiation.

The perceptual conflict hypothesis (e.g., Hock & Egeth, 1970) assumes that the subject is unable to completely restrict his attention to the relevant aspect of the stimulus. Processing the irrelevant word information disrupts or delays the processing of the relevant color information due to the division of a limited processing capacity between the two types of information, or due to the serial processing of the two different inputs with the irrelevant information gaining prior entry under some circumstances and, thus, holding up the processing the relevant information. Both explanations are consistent with Treisman's (1969) postulate of an automatic encoding of all incoming information.

Timing during the encoding process is a critical factor for the perceptual conflict explanation. Any manipulation that affects the encoding time of either aspect of the colored word will help determine the

amount of interference or distraction. Simple tasks such as color counting or scanning allow for rapid encoding and leave little opportunity for irrelevant printed material to interfere (Egeth, Blecker, & Kamlet, 1969; Pritchatt, 1968). Higher level cognitive tasks, such as the Stroop task or the Sternberg task (Sternberg, 1967), require relevant stimulus encoding to proceed more slowly and, thereby, allow a greater opportunity for the irrelevant word information to interfere (Hock & Egeth, 1970).

According to the response competition hypothesis (e.g., Dalrymple-Alford & Azkoul, 1972; Klein, 1964; Morton, 1969), interference in the Stroop task occurs because the subject must suppress his response to the irrelevant word before he can initiate his response to color. Interference results whenever the irrelevant information is processed more rapidly than the relevant information and, therefore, reaches the response initiation stage first. The more rapid processing of the irrelevant information occurs when the relevant stimulus information must be recoded into a form suitable for making the required response when the irrelevant information is already in that form. In the Stroop task, the word is already in verbal form, but the relevant color information requires a transformation from a perceptual to a verbal code (Treisman & Fearnley, 1969). Support for this hypothesis is in the finding that verbal responses to words are much more rapid than color naming (Cattell, 1886; Fraisse, 1969; Ligon, 1932; Stroop, 1935). The response competition hypothesis, therefore, proposes that because the irrelevant word stimulus is processed faster, it arrives at the response initiation point before the relevant color stimulus. Response to the irrelevant information must be inhibited to allow the relevant stimulus to catch up and elicit the correct verbal response. It is the need to inhibit the response to the irrelevant information which slows the responses of the subject and decreases accuracy (Klein, 1964; Morton, 1969).

From the above description, it should be clear that

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processing time during perception plays a role in the response competition hypothesis that is as important as its role in the perceptual conflict hypothesis. Since, according to this approach, interference will occur only when the irrelevant word information is processed first (Dalrymple-Alford & Azkoul, 1972; Morton, 1969), factors which affect the speed of processing of the relevant or irrelevant information will determine whether or not, and how much, interference will occur. For example, Klein (1964) has suggested that the amount of response competition depends on the attentive, or attention-catching, qualities of the irrelevant stimulus information. The greater the attentivity, the faster the irrelevant information will be processed and the greater the resulting interference.

The similarity of the required response and the response to the interfering material also has an effect on the processing time. Color identification has been found to be interfered with only slightly by nonsense syllables and noncolor-related words, but markedly when the irrelevant words are closely related in their meaning to color or when they make a direct reference to color. The greater interference occurs when the words are from the same set of colors as those to be identified (Klein, 1964). The greater interference of the more similar material is thought to result from priming, an increase in the availability of responses to the stimulus material due to their associative link with previously emitted responses (Klein, 1964; Morton, 1969).

It may be possible to test hypotheses by varying relevant and irrelevant processing time differentially. Several studies have attempted to do that by manipulating the time required to process the interfering words. That was done by varying the recognizability of the irrelevant words, by preexposing them to the subject, by introducing a mask, by varying the background luminance, and by manipulating the frequency of occurrence and meaningfulness of the words (Bakan & Alperson, 1967; Dyer, 1971; Gumenik & Glass; Dyer, Note 1, 1970). All of these studies show a decrease in interference with a decrease in the attentivity of the irrelevant words. Unfortunately, such results can be explained equally well by both hypotheses. Since the word information is more difficult to encode, it should take longer to process it completely, and, therefore, either less of it would be picked up for processing, producing less perceptual conflict, or it would be delayed in processing, allowing the relevant information to reach the response initiation stage first.

A few studies have attempted to slow down the perceptual processing time of the color dimension (Golden, 1974; Hock & Egeth, 1970; Ray, 1974). The results of these studies are equivocal; both no effect and an increase in the amount of interference have been reported.

While studies which manipulate either word or color processing time provide important data, neither provides adequate information about how the processing time determines Stroop task performance if there is an interaction between them. To examine these possible interactive effects, it is necessary to vary the processing time of the relevant and irrelevant stimuli factorially.

Choice reaction time results indicate that the time it takes to process simple color or geometrical stimuli is a linear function of the amount of information in the stimulus set (Teichner & Krebs, 1974). Teichner and Krebs further demonstrated that the information function becomes less and less steep with practice. Since, in the college population, words can be assumed to be associated with more practice than naming colors, the information function for words would be expected to be less steep than the information function for colors. In fact, Gholson and Hohle (1968) have shown this to be true. They found that reaction time for color naming linearly increased with the amount of information while the reaction time for color words levels off. On this basis, it is reasonable to expect that increase in the amount of word and of color information in the Stroop task increases the processing time of each accordingly. If word and color information were varied factorially in amount, both the effects of differential processing times and their interaction could be used as a basis for evaluating the two hypotheses: This was the approach of the present experiment.

Each hypothesis results in a somewhat different set of predictions of the effects of altered processing times resulting from varying amounts of word and color information. These predictions are illustrated in Figure 1. The perceptual conflict approach views increases in stimulus information, relevant or irrel-

Figure 1. Predictions deduced from the perceptual conflict hypothesis and the response competition hypothesis based on the effects on interference by word and color information: (a) perceptual conflict; (b) response competition with priming emphasized (solid line) and with information load emphasized (dotted line).

evant, as increasing the processing load in a limited-capacity system. Therefore, as shown in Figure 1a, this model would predict an increase in interference with either an increase in color or word processing time. Since tasks with a large cognitive load would increase encoding time and permit increasing amount of irrelevant material to enter and further overload the system, this approach would also predict a fanning effect when the irrelevant and relevant information are simultaneously increased.

Predictions from the response competition hypothesis must account for the interaction of two conflicting variables, information loading and priming of the irrelevant stimuli. Increases in color information, as shown in Figure 1b, and consequently color processing time, should slow color processing relative to word processing, and thereby increase interference. Increases in the information load of the irrelevant words should decrease the amount of interference as it would increase word processing time, allowing the color information to be processed and to reach the response initiation stage before the word.

Priming of the responses to the irrelevant stimuli should cause Stroop interference to be a function of the amount of overlap of the irrelevant word set and the relevant color set. Interference should increase as the irrelevant set becomes increasingly similar to the relevant set. When the irrelevant and relevant stimulus sets are identical, the greatest amount of priming of the irrelevant word information and interference from these words should occur.

Since there is no basis for determining which of the two processes, information loading or priming, should have the greater effect, two sets of predictions were made for the response competition hypothesis. The solid lines of Figure 1b show the predictions when the heavier weighting is placed on priming effects. As can be seen, it can be predicted that there should be a decrease in interference with increases in irrelevant information for a constant 1 bit of color information. For a constant 2 bits of color information, the amount of interference first increases and then decreases as the irrelevant word set increases and then decreases in similarity to the relevant color set. Finally, for 3 bits of color information, there should be a slight increase in interference as the irrelevant information increasingly overlaps the relevant information.

When information loading is given a relatively greater weight than response priming, as shown by the dotted lines in Figure 1b, the response competition model would predict a decrease in interference with increases in irrelevant word set size. The greatest amount of interference for each level of color information would be predicted for conditions with the least amount of irrelevant word information and the

greatest amount of overlap between the color and word stimulus sets.

This experiment was intended to evaluate the two interpretations of the Stroop phenomenon by factorially varying the amount of relevant and irrelevant information in the Stroop task and to compare the obtained results with the above sets of predictions.

METHOD

Subjects

A total of 110 subjects volunteered to participate in the study as partial fulfillment of a methodology requirement in an introductory psychology course. All subjects were screened for color defects prior to participation in the experiment, and two subjects found to be color weak were eliminated.

Stimuli

The stimuli were nine decks of 6×9 in. (15.24×22.86 cm) white index cards. Each deck consisted of: (1) a set of three Stroop cards in which color names were written in incongruously colored ink, (2) three color word control cards in which color names were written in congruously colored ink, and (3) three color-symbol control cards in which the stimuli were strings of colored Os of the same lengths as the color names. Each stimulus card contained 80 color names or 80 groups of colored Os.

The nine decks of stimulus cards corresponded to the nine experimental conditions, which were defined by factorially varying the amount of irrelevant word information present in the Stroop cards, either 1, 2, or 3 bits of information (2, 4, or 8 equiprobable color names), and the amount of relevant color information present in the Stroop and control cards, either 1, 2, or 3 bits of information (2, 4, or 8 equiprobable colors). The colors BLUE and GREEN were used for the 1-bit color and the 1-bit word conditions. BLUE, GREEN, ORANGE, and GOLD were used in the 2-bit conditions, with the addition of the colors RED, PINK, BROWN, and BLACK for the 3-bit conditions. For illustration, the stimulus deck for the 1-bit word and 2-bit color information condition had Stroop cards with the color names BLUE and GREEN printed incongruously in BLUE, GREEN, ORANGE, and GOLD ink. The control cards for this condition contained symbols or congruent color names written in these same four colors of ink. The prescribed color names and inks were randomly distributed on the cards, with restrictions that all colors on any card be used an equal number of times.

Procedure

The experiment was a 3 by 3 by 3 mixed design with two between-subject variables and one within-subject variable. There were nine groups of subjects, with the amount of relevant and irrelevant information, 1, 2, or 3 bits, varied between subjects. The type of stimulus card, Stroop, color symbol, or color word, was a within-subjects variable.

At the onset of the experimental session, the subjects was presented with the deck of cards turned over so that the stimuli were not visible. Upon an oral signal from the experimenter, the subject turned the top card over so that the stimuli were visible. At the sound of a click, which initiated a millisecond timer, the subject began identifying the colors of ink in which the color words or symbols were written. The subjects identified the colors one at a time, proceeding in a left-to-right direction. When the subject finished identifying the final color on the card, the experimenter pressed a button which stopped the timer. The subjects were instructed to respond as quickly as possible without making errors. In the advent of an error, the subjects were to continue in the assigned task without correction. The stimulus

deck was presented three times, resulting in 27 trials divided into three trial blocks. The order of presentation of the cards within the stimulus deck was randomized from one trial block to the next. Response time and number of errors were recorded for each stimulus card.

Prior to the experiment proper, the subjects were presented with two practice cards, one Stroop and one color symbol, containing 16 stimuli each. The two practice trials were used to ensure that the subjects understood the procedure and the instructions.

RESULTS

The subjects made very few errors regardless of type of stimulus card or experimental condition. The maximum was 3% error per stimulus card; the average error was less than 2%. Because the error rate was so low, further analyses were restricted to response times.

Since irrelevant word information was manipulated only in the Stroop cards, two separate analyses of variance were conducted on the response times. One analysis of variance in which irrelevant word information was not considered as a variable was conducted over response times to all three types of stimulus cards, Stroop, color symbol, and color word. The other analysis of variance, which examined the effects of irrelevant word information was conducted over the response times to only the Stroop cards.

The response times for the three types of stimulus cards are presented in Figure 2 as a function of the amount of relevant stimulus information. As can be seen, the response times of the Stroop cards were longer than those for the color-symbol and congruous color-word cards. The differences were significant, $F(2,105) = 75.26$, $p < .001$. While response times to all three types of cards tended to increase as a function of amount of relevant color information, the magnitude of the increase varied with the type of stimulus card. Increases in response time were greatest for the Stroop cards, followed by the color-symbol and then the color-word cards. The interaction between type of stimulus card and the amount of relevant color information was significant, $F(4,210) = 51.23$, $p < .001$.

A comparison of the main effects of the amount of irrelevant word information and relevant color information in the Stroop cards is presented in Figure 3. Both main effects are presented in this figure to allow for a convenient comparison. The figure should not be used to make inferences about an interaction between these two variables since each point in the figure represents the main effects of the variable under consideration, collapsed across the three levels of the other variable. As shown, response time increase in a linear fashion with the amount of relevant color information, $F(2,99) = 101.36$, $p < .001$, while increases in irrelevant word information produced only a slight increase in response time. The

Figure 2. Mean response time for the Stroop, color-symbol, and color-word stimuli as a function of relevant (color) stimulus information.

main effect of irrelevant information was not significant and there no significant interactions of this variable with any of the other variables under consideration.

Figure 3. Main effects of relevant (color) and irrelevant (word) stimulus information on response time.

There was a significant decrease in response time as a function of practice, $F(2,210) = 133.41$, $p < .001$, and a significant interaction of response block with the type of stimulus card, $F(4,420) = 2.34$, $p < .05$. Newman-Keuls multiple comparisons indicated that the decrease in response time as a function of practice was restricted to the first trial block for the two control sets of cards ($p < .05$). Response times for the Stroop cards continued to decrease over the remaining trial blocks.

Interference in the Stroop task is usually defined as the difference in the subject's response times between when he identifies the color of ink in which incongruently colored color names are printed, Stroop cards, and when he identifies the colors of ink of colored symbols, i.e., the color-symbol cards. Difference scores were calculated and an analysis of variance of the response times was conducted. Although the previously presented response times are not directly relevant to a test of predictions, they should allow the reader to examine the difference scores in relation to the absolute scores and, thereby, add confidence to an interpretation of the difference scores.

Plotted in Figure 4 is a comparison of the difference-score main effects of the amount of irrelevant information and relevant color information. As with Figure 3, this figure presents the main effects of the relevant and irrelevant information and should not be interpreted as the interaction between these variables. The difference scores which provide a more sensitive measure of interference in the Stroop task suggest not only a linear increase as a function of the amount of relevant color information, $F(2,99) = 63.89$, $p < .001$, but also indicate an increase as a function of the amount of irrelevant word information, $F(2,99) = 23.48$, $p < .001$.

The interaction between the amount of relevant and the amount of irrelevant information is presented in Figure 5. The decrement in performance of groups receiving 1 bit of relevant color information remained relatively constant across all levels of irrelevant word information. Groups of subjects receiving either 2 or 3 bits of relevant color information, on the other hand, showed increased interference with increases in irrelevant word information. The interaction between color information and word information was significant, $F(4,99) = 9.70$, $p < .001$.

The only other significant main or interactive effects in the difference scores were those associated with practice. The difference scores, like the absolute scores were significantly decreased by practice, $F(2,198) = 49.01$, $p < .001$, and there was a significant interaction between the amount of practice and the amount of relevant color information present in the stimulus, $F(4,198) = 2.83$, $p < .05$. A Newman-

Figure 4. Main effects of relevant (color) and irrelevant (word) stimulus information on interference plotted as difference scores.

Keuls test for multiple comparisons conducted over these data suggested that the difference scores decreased with practice in all except the smallest information condition ($p < .05$).

Figure 5. Mean interference plotted as difference scores as a function of relevant (color) and irrelevant (word) stimulus information.

DISCUSSION

The results of this study indicate that interference in the Stroop task is a function of both the amount of relevant color information and irrelevant word information. Assuming that the amount of time it takes to process a stimulus is a function of the amount of information in the stimulus set (Gholson & Hohle, 1968; Teichner & Krebs, 1974), the results indicate that Stroop task interference is a function of the perceptual processing time of both the task-relevant and the task-irrelevant information.

The finding that Stroop task interference is a function of the word processing time is not new. For example, Bakan and Alperson (1967), Dyer (1971), Gumenik and Glass (1970) and Dyer (Note 1) have found that Stroop task performance is improved by qualitative manipulations which degrade the irrelevant words. The current study has extended those findings by demonstrating that Stroop interference increases with increases in irrelevant stimulus information, a quantitative factor.

Attempts to demonstrate that Stroop task interference depends upon the relevant color information have produced equivocal results. Two previous attempts (Golden, 1974; Ray, 1974) to manipulate color processing time by varying the amount of information in the relevant color set failed. In both of these studies, however, information set was varied as a within-subjects variable. Since the subjects experienced all sets, it is possible that their responses were based upon the largest set size as a point of reference. That likelihood has been analyzed in detail in a different context by Kornblum (1973). An effect might have been found in these studies if a between-subjects design had been used.

Although they have been criticized (Dalrymple-Alford & Azkoul, 1972; Dyer, 1973) for the interpretation of their data and for not using a traditional form of the Stroop task, Hock and Egeth (1970) manipulated perceptual processing time by varying the size of the relevant color set in a Sternberg (1967) binary classification memory task. Comparisons were made among sets of Stroop stimuli or colored $\times$ s or common verbs written in different colors of ink. The subject's task was to indicate whether or not the color of the stimulus items was a member of the target set; the target set had been defined as one, two, or three colors. It was found that the response times were a linear function of the relevant set size and that the differences among the three types of stimuli were in the intercept but not in the slopes of the function. In accordance with Sternberg's model, Hock and Egeth interpreted their data as indicating that the locus of interference in the Stroop task is in the encoding of the stimulus information. In fact, the Sternberg model deliberate-

ly confounds both stimulus encoding and response processing in the intercept of the function. Their results, therefore, do not really distinguish between the perceptual conflict and response inhibition hypotheses. The finding of a relevant stimulus information function, however, is acceptable and in agreement with the present results.

The finding of increases in interference with increases in relevant stimulus information is not consistent with the hypothesis of Ray (1974). Ray proposed that it is the absolute speed of the response to the word dimension alone which determines Stroop task interference. The present finding of a steeper slope for the relevant color information function than for the irrelevant word information function suggests that the perceptual processing time of the relevant color information not only partially determines Stroop interference but plays an even more important role in this interference than does the processing time of the irrelevant word information.

The finding of an increase in interference with an increase in the amount of relevant color information would have been predicted by either the responses competition or the perceptual conflict hypothesis. Both approaches require that an increase in the perceptual processing time of the task-relevant stimulus should result in an increase in the amount of interference produced by the task-irrelevant information. However, the finding that increasing amounts of information in the task-irrelevant stimuli also increased interference would have been predicted by the perceptual conflict hypothesis, but not by the response competition hypothesis. According to the latter, an increased perceptual processing time of the irrelevant word should have decreased interference by allowing the relevant color information time to reach the response initiation stage unimpeded. On the other hand, for the perceptual conflict hypothesis which assumes a limited processing capacity, any increase in the stimulus information load, whether relevant or irrelevant, would be expected to increase the perceptual processing time of the stimulus since only a limited amount of information can be processed within a given time interval. The increase in response time, relative to the control then would result from an increase in interference from the irrelevant stimulus.

Of even greater importance for testing the predictions of the two hypotheses is the interaction observed between the amount of relevant and the amount of irrelevant information. Both the perceptual conflict and the response competition approaches would have predicted a more or less flat slope as a function of increases in irrelevant word information for subjects receiving only 1 bit of color information. The subjects in this condition had

a minimal amount of relevant stimulus information to process, and the responses to this information should have been readily available since subjects had only two possible responses, BLUE and GREEN. The results for the groups receiving 2 and 3 bits of color information can be explained only by the perceptual conflict hypothesis. Although the obtained data did not show the fanning effect predicted by the perceptual conflict hypothesis, the general trend of the data agree with the predictions. Stroop task interference increased as a function of both relevant color and irrelevant word information.

As can be seen from Figure 1b, the response competition hypothesis would have predicted either a flat slope or a decrease in interference as a function of increases in irrelevant word information. That hypothesis would postulate the operation of two conflicting variables, information loading and priming of the irrelevant stimuli, in the 2- and 3-bit color information conditions. While the response competition hypothesis might be able to explain the findings for the 3-bit color information conditions by emphasizing the effect of priming i.e., an increasing interference with increases in the similarity of the irrelevant stimulus set to the relevant stimulus set, it cannot account for the results obtained for the 2-bit color information condition. In changing from 2 to 3 bits of irrelevant word information, both priming and information loading would be predicted to decrease interference. That is, as the irrelevant word set increases beyond the relevant color set and, responses to the nonoverlapping color words should not be as readily available and the increased information load should slow the processing of the irrelevant words, preventing them from reaching the response initiation stage before the color stimuli. The obtained results, however, indicate that the interference in performance continues to increase with increased information load, at least over the range used.

The only way in which the response competition model could account for all of the data would be to postulate that the ease with which the subject can inhibit a response to the irrelevant word is dependent on the information load of the irrelevant stimulus set. The smaller the information load, the easier it would be for the subject to anticipate the irrelevant material and inhibit a response to it. As the amount of irrelevant stimulus information increases, uncertainty about the irrelevant stimulus would increase, making it more difficult for the subject to block a response to this stimulus at the response initiation stage. This increased difficulty in response inhibition with increased irrelevant stimulus information would be reflected in increased response time and/or incorrect responses. While this postulate allows the response competition model to handle the present findings, it increases the complexity of

the model and does not seem to increase the ability of the model to predict beyond the assumption of a limited processing capacity.

In conclusion, the results of this experiment appear to support a perceptual conflict explanation of Stroop task interference. The finding that increasing the information load of either the relevant or the irrelevant stimuli increases interference suggests interference during the encoding of information rather than during the later stage of response initiation. The occurrence of this form of interference, due to limited encoding capacity, does not, however, rule out other types of interference. While there is no evidence in the present study to indicate that response competition does exist, failure to find such evidence does not rule out the possibility that response competition of some sort can and does take place. Numerous studies on the Stroop task and related phenomena (e.g., Dalrymple-Alford & Azkoul, 1972; Egeth, Blecker, & Kamlet, 1969; Hodge, 1973) indicate that interference is dependent on the type of response required. Combining the results of these studies with the present findings, supporting Stroop interference at the perceptual encoding stage, a combined perceptual and response competition approach is suggested. An initial attempt at combining these hypotheses has been made by Dyer (1973), who suggests that Stroop task interference involves both response competition and a failure of the subject to selectively attend to the relevant stimulus. Further research in relating these two processes needs to be done; however, before the exact role of these two processes can be examined further, the concepts themselves need to be made operationally more specific.

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