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STROOP INTERFERENCE: AN INPUT AND AN OUTPUT PHENOMENON

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Three theories of Stroop interference are considered: perceptual conflict theory (Hock and Egeth, 1970), response competition theory (Morton, 1969) and conceptual encoding theory (Seymour, 1977). The first two fail to provide a full explanation of the available data, and Seymour's evidence is incomplete. Two experiments are reported. In the first, typical Stroop interference occurs in naming colour patches. In the second, subjects responded to colour patches with learned letter name responses. Both stimulus-related (incongruent colour names) and response-related (incongruent letters) distractors produced interference. These results indicate that any theory which assumes only a single locus for interference is incomplete. Conceptual encoding conflict and a modified form of response competition are suggested as possible dual mechanisms for Stroop interference effects.

Introduction

The Stroop colour-word test (Stroop, 1935) reveals a limitation in the processing of ambiguous visual stimuli; subjects take longer to name the hue of a colour-word stimulus (e.g. the word RED written in green ink), than that of a plain colour patch. This interference effect increases with the semantic relatedness of the distractor word and the hue name, and is greatest when the distractor word is a member of the set of response names (Klein, 1964). When the distractor word is identical to the hue name the response is facilitated (Dyer, 1973). Several theoretical accounts of the Stroop interference effect have been put forward and three of them will be discussed here.

Perceptual conflict theory

Hock and Egeth (1970) suggest that semantic information in the stimulus disrupts the identification or encoding of the ink colour by diverting attention from it. The disruptive power of the distractor is proportional to the degree of semantic relatedness between it and the required response, the subjects being sensitised to words related to the semantic domain of the task. This theory is unable to explain why congruent stimuli, i.e. those in which the distractor word is the same as the hue name, do not cause interference, and may even facilitate the response.

The Logogen model

Response competition theories of Stroop interference suggest that interference occurs at the level of the processes involved in generating responses from their

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representations in memory. The model most frequently used to elucidate the response interference effect is Morton's Logogen system (Morton, 1969, 1970; Warren, 1972). Activation of a logogen puts a program for verbal production of a particular word into a response buffer, which has capacity for only one such program.

If one program becomes available before another the output of the second will be delayed until the buffer is cleared. Interference in the Stroop test is caused by the activation of two logogens, corresponding to the colour* and the distractor. The required response in this case is the colour name, and to the extent that the program for the distractor becomes available before that for the colour name, production of the colour name response will be delayed. Interference is thus more probable when the distractor is processed faster than the relevant stimuls. Distractors that are semantically related to the task will be processed faster than those that are not, as their logogens will have been primed via associations in semantic memory (Morton, 1969). Reading responses will interfere with naming responses as reading is generally faster than naming (Cattell, 1886; Fraisse, 1969), although this may be reversed if the processing of the distractor word is delayed by degradation, (Gumenick and Glass, 1970) or the nonverbal aspect is such that it can be processed faster than the verbal aspect (Palef and Olson, 1975).

What is not made clear in this model is why the response to the distractor is not actually *output* on the trials when it arrives first in the buffer. If it is assumed that either the distractor related response always arrives first and is rejected on that basis, or that responses are tagged as to their origin and that responses with word tags are rejected, this difficulty may be resolved. However, the logogen model as presently stated has no decision mechanism in the response buffer, and even if it had, neither of these modifications could explain the fact that responses to items in which the colour and distractor are the same are facilitated.

Conceptual encoding theory

This theory (Seymour, 1977) places the locus of interference between the sites proposed by the previous two theories. Seymour (1973) regards the logogen system as a mechanism for converting internal representations from one code to another. According to the theory Stroop stimuli give rise to two perceptual codes. One is a graphemic code produced by the distractor word that allows access to a conceptual code in semantic memory via the Logogen system. The other is a pictorial code produced by the colour that allows access to a conceptual code in semantic memory via the "Iconogen system", a system of logogen-like units for pictures. A conceptual code may be considered to be a constellation of semantic features. Semantically related items will thus access conceptual codes that have features in common and can be said to "overlap" on particular semantic dimensions. The Stroop task requires the retrieval of a single conceptual code that can be converted, via the Logogen system, into an articulatory code that is used to generate the naming response. The conceptual codes accessed by a Stroop stimulus overlap

* According to Morton (1970) all verbal responses are mediated by the Logogen system although stimulus identification may proceed differently for nonverbal stimuli.

in many ways, and time is required to "disambiguate" them and to select a single code for conversion into a response. The greater the degree of conceptual overlap, the longer the disambiguation process will take. Stroop interference is the result of this increased processing time. The theory gives no account of the disambiguation process and it is unclear on what grounds the irrelevant code is selected for deletion.

The conceptual encoding theory is, however, capable of explaining the congruency effect. Seymour suggests that the two aspects of a congruent stimulus access the same conceptual code, and that retrieval of this code is thus facilitated.

Input and output effects; Seymour's experiments

In the orthodox Stroop task, distractor words are all members of the set of response names. It is thus difficult to dissociate the effect of a distractor on the encoding of the *stimulus* from its effect on the production of a name *response*. The stimulus, distractor and response all belong to the same region of semantic space (colours in this case), and as the task can only be performed with some reference to semantic memory, directly or via the Logogen system, input and output effects are inseparable. The semantic domains of stimuli and responses may be separated if subjects are taught new names for the stimuli that are semantically *unrelated* to their habitual names.

Seymour (1977) requested subjects to respond to colour patches with *related* season names. He showed, in a pilot study, that there are semantic associations between the colours white, green, yellow and brown, and the season names Winter, Spring, Summer and Autumn respectively. He also points out that the four seasons fall naturally into two opposite pairs, Winter/Summer and Spring/Autumn. Thus the colours and season names may be considered to be four paired-associate clusters with some degree of semantic oppositeness between certain clusters,

Seymour's tasks can be divided into *unmediated tasks* in which the response is derived from the stimulus via a single direct association, and *mediated tasks* where two or more successive associations are required (Table I).

Two findings support the conceptual encoding theory. In the unmediated tasks, responses to stimuli related to the distractor are faster than those to stimuli unrelated to the distractor. The Logogen model would also predict this result, but perceptual conflict theory would not. In the mediated tasks the same result is obtained. This result is evidence against response competition theory which would predict that responses would be faster when the distractor is the same as the appropriate response

e.g. AUTUMN GREEN ⟶ "AUTUMN"

There are three difficulties with Seymour's experiments. Firstly, although a congruency effect is found in the unmediated tasks its origin is unclear. In a colour naming task when the word is RED and the colour is red it is clearly possible that both stimulus aspects access the same conceptual code. However, season names and colours (e.g. SPRING and green) though related, are conceptually distinct. As presently proposed the process of conceptual encoding does not allow these two stimulus aspects to access the same code directly. Secondly there is no condition in which the distractor is semantically neutral with respect to colours included in

TABLE I

Nature of naming tasks in Seymour's experiments

		Unmediated (direct)		Mediated (indirect)
Experiment I	Stimulus	Colour	Stimulus	Colour
	Response	Associated season	Response	Season opposite associated season
	Distractor	Season name	Distractor	Season name
Experiment II	Stimulus	Season	Stimulus	Season
	Response	Associated colour	Response	Colour associated with the opposite season
	Distractor	Colour	Distractor	Colour
Experiment III	Stimulus	Season	Stimulus	Colour
	Response	Opposite season	Response	Colour associated with the season opposite that associated with the stimulus colour
	Distractor	Colour	Distractor	Season name

these tasks. It is therefore impossible to tell whether the related distractors facilitate the reaction, or the unrelated ones delay the reaction. Conceptual facilitation or conceptual conflict or both may be present.

Thirdly, unrelated distractors in these tasks have distinctly different relationships with the relevant stimulus. For example, in the colour naming tasks (Experiment I) an unrelated distractor could be the name of the season chronologically *before* or *after* the season related to the colour, or *opposite* that related to the colour. Seymour points out that the "opposite" relation slows response more than "before" or "after" which is consistent with the conceptual encoding model but not with response competition. Such a semantic oppositeness effect (SOE) occurs most strongly in the mediated tasks for Experiments I and II, where the mean difference between opposite and adjacent distractors is 30 ms, and 61·5 ms, respectively. The mean SOE in the mediated task of Experiment III is only 16 ms. There is no clear evidence of a mean SOE in any of the unmediated tasks.

The reason for this pattern of results is unclear. The SOE may be produced by processes that act too slowly to affect the relatively fast unmediated responses, but fast enough to affect mediated responses. This explanation is supported by the size of the SOE in the mediated task of Experiment III, in which RT's are almost as fast as those in the unmediated tasks.

The fact that the SOE occurs in some tasks but not in others raises two difficulties for Seymour's conclusions that interference and facilitation effects can be entirely accounted for by the conceptual encoding theory, and that response related effects do not occur.

Firstly, if interference effects are solely due to conceptual encoding conflict, and this conflict is greater when the distractor and stimulus are represented in memory as semantic opposites, then the SOE should occur in all tasks.

Secondly, and more importantly, the presence of the SOE may actually *conceal* response related effects. In the mediated tasks which show the SOE the *opposite* distractors are identical with the response. The SOE might mask the response facilitation expected from response effects in this case. It may be argued that the existence of oppositeness among the stimuli used is a disadvantage from the point of view of testing conceptual encoding theory, since it obscures attempts to decide whether, in addition to conceptual encoding effects, there are response effects.

A test of conceptual encoding theory

The present experiments were designed to test the conceptual encoding explanation of the Stroop effect, using stimuli and responses whose domains are entirely semantically unrelated. A neutral condition was included so that the conflicting or facilitating nature of the effects would be clear. Subjects were taught new and arbitrary verbal responses to colour patches. The colours used were red, green and blue, and the responses that were randomly allocated to these colours were the letter names "D", "I" and "X". Distractors could be congruent, incongruent, irrelevant or neutral with respect to the stimulus, or with respect to the response. Congruent and incongruent distractors were colour names and rows of four identical letters that were members of the stimulus set and response set respectively. Irrelevant distractors were colour names or letter strings that were not members of these sets. Neutral distractors were rows of four plus signs.

Response related distractors should have no specific effect on encoding and stimulus related distractors should have no specific effect on response production. If interference occurs only during stages of encoding the stimulus, the colour-word distractors should produce more interference than letter distractors. If interference occurs only during response production, then letter distractors should interfere more than colour name distractors. Similarly the locus of facilitation effects can be investigated. The first experiment was run to check that the stimuli used did produce normal Stroop interference, and that letter distractors had no unusual relation to the colour naming task domain.

Experiment I

Method

Subjects

Three male and three female members of London University, with ages ranging from 20 to 45 years, were run individually in a single half-hour session. They received standard experimental rates of pay.

Materials

Stimuli were printed centrally on white card in appropriately coloured felt tip pens. The three colours used were red, green and blue. A single stimulus measured up to 2·5 cm in length and was 0·7 cm high. Distractor items were the words RED, GREEN and BLUE for the congruent and incongruent words; BROWN, ORANGE and PINK for the irrelevant words; DDDD, IIII, XXXX, NNNN, OOOO and AAAA for the irrelevant letters condition. (Letters were completely unrelated to stimulus or response in this task, as the response was normal colour naming). Neutral stimuli were a row of four plus signs, ++++. Six stimuli in each colour were made for each of the above conditions, yielding 90 stimuli in all.

Design

Five conditions were used:

1. Congruent colour words (e.g. RED written in red ink)
2. Incongruent colour words (e.g. GREEN written in red ink)
3. Irrelevant colour words (e.g. BROWN written in red ink)
4. Irrelevant letter strings (e.g. DDDD written in red ink)
5. Neutral stimuli (e.g. ++++ written in red ink)

Eighteen stimuli were prepared for each condition, there being three possible congruent word stimuli, six possible incongruent word stimuli, nine possible irrelevant word stimuli, 18 possible irrelevant letter stimuli and three possible neutral stimuli. The set of 90 stimuli were presented in three trial blocks of thirty trials each with a short break between blocks. Each block was preceded by the presentation of three neutral practice stimuli, one in each colour. The order of presentation of stimuli was randomised with the constraint that no stimulus should be repeated on consecutive trials. Subjects responded to a set of 24 neutral practice stimuli before the experimental stimuli were presented.

Procedure

Subjects were seated at a two-field Cambridge tachistoscope in a well-lit room, and were fitted with a throat microphone which operated a voice key. Subjects were instructed to name the hue of each stimulus as fast and as accurately as possible. On each trial the experiment said "Now"; within 0·5 s a single stimulus was presented in the region of central fixation at maximum field illumination, at a viewing distance of 61 cm (visual angle 2·4°). Presentation of the stimuli started a Venner millisecond timer which was stopped by activation of the voice switch. The block of 24 practice trials was followed by the three experimental trial blocks. Within a block there were approximately 10 s intervals between trial onsets, and there was a mean interval of 1 min between blocks. Reaction time, stimulus and errors were recorded.

Results

Table II gives mean vocal reaction times in ms.

TABLE II

Mean naming latency (ms) (underlining indicates means that are not significantly different at the 0·01 level, two tailed)

		Condition		
Neutral	Congruent colour name	Irrelevant letter string	Irrelevant colour name	Incongruent colour name
559	601	639	765	782

A one factor between-subject one factor within-subject ANOVA was performed. The factor of sex of subject was not significant ($P > 0{\cdot}4$) and the results were pooled across subjects. The factor of conditions was highly significant ($F(4,4) = 26$, $P < 0{\cdot}0001$). The interaction was not significant.

The occurrence of Stroop interference can be determined by testing the difference between mean RTs for the incongruous word condition and the neutral condition. This difference is significant (Scheffé test $F'(1,16) = 65{\cdot}25$, $P < 0{\cdot}001$). Irrelevant colour words also cause an interference effect compared to the neutral condition (Scheffé test $F'(1,16) = 55{\cdot}5$, $P < 0{\cdot}001$) indicating that a semantic associative effect occurs in this task. There is no facilitation effect in this task as the congruent word condition is slower than the neutral condition, but there is a congruency effect as the former condition causes no significant interference.

The irrelevant letters condition is significantly slower than the neutral condition (Scheffé test $F'(1,16) = 18{\cdot}42$, $P < 0{\cdot}025$), but the degree of interference is far less than that for irrelevant colour words as the difference between these conditions is also significant (Scheffé test $F'(1,16) = 20{\cdot}67$, $P < 0{\cdot}001$).

Eighteen errors were made (3·3%) and the voice key failed to stop the timer on one occasion. Latencies for these trials were omitted from the analysis. Of the eighteen errors thirteen were fast naming (mean VRT 478 ms) of the background item, in all cases an incongruent colour word distractor, and five were wrong responses with fairly slow latencies (mean VRT 650 ms).

Discussion

The hypothesis that these stimuli can generate Stroop interference is supported The lack of facilitation in the congruent word condition is unfortunate, but this effect has always been elusive (Dyer, 1973). However, a general congruency effect is clear as congruent distractors cause no more interference than the neutral plus signs. The difference between incongruent and irrelevant words is not significant, but lies in the right direction (Klein, 1964). It should also be noted that the irrelevant letter stimuli, although slowing VRT to some extent, led to relatively little interference in comparison with incongruous and irrelevant colour word distractors. The effect that they do have may be due to their being more meaningful than the neutral + signs, or to the relative novelty of any one of the letter string distractors, as each string only appeared once in each colour. There is no reason to suppose that these letters have any particular relationship to the task of colour naming.

The second experiment was run to test Seymour's conceptual encoding theory. Subjects were taught to respond to colour patches with letter names.

Experiment II

Method

Subjects

Six male and six female subjects, members of London University, aged between 20 and 40 years, were tested individually for a single one hour session for which they received standard experimental rates of pay.

Materials

The stimuli were the same type as those used in Experiment I. The names "D", "I" and "X" were assigned to the colours red, green and blue according to two 3 × 6 Latin square designs, one for male subjects and one for female subjects. Eighteen stimuli were used for each of seven conditions, the exact stimuli in the congruent and incongruent letter conditions depending on the colour-letter assignment for each subject. The resulting 126 stimuli were presented in three blocks of 42 trials each. Each block was preceded by three neutral practice stimuli.

Design

Seven conditions were employed:

1. Congruent words (e.g. RED in red ink)
2. Congruent letters (e.g. DDDD in red ink, when "D" is the response to red)
3. Incongruent words (e.g. GREEN in red ink)
4. Incongruent letters (e.g. XXXX in red ink, when "D" is the response to red)
5. Irrelevant words (e.g. BROWN in red ink)
6. Irrelevant letters (e.g. NNNN in red ink)
7. Neutral stimuli (e.g. ++++ in red ink)

For any one colour-letter assignment there were three possible congruent letter stimuli, six possible incongruent letter stimuli and nine possible irrelevant letter stimuli (in this condition only N, O and A were used). The number of possible stimuli in the other conditions remained the same as for Experiment I. Eighteen stimuli were used in each condition yielding 126 experimental stimuli.

Procedure

The procedure was the same as that used in Experiment I, except that the 24 practice trials were replaced with learning trials, using neutral stimuli, to a criterion of 10 successive correct trials, or a minimum of thirty and a maximum of 50 learning trials. There were three practice trials before each block of 42 experimental trials.

Results

Table III gives mean vocal reaction times in ms.

TABLE III

Mean naming latency (ms) (underlining indicates means that are not significantly different at the 0·01 *level, two tailed)*

Condition: Congruent letter string	Congruent colour name	Neutral	Irrelevant letter string	Irrelevant colour name	Incongruent colour name	Incongruent letter string
749	759	794	816	823	834	916

A one factor between subject, one factor within subject ANOVA was performed. The factor of sex of subject was not significant ($P > 0{\cdot}5$) and the results were pooled across subjects. The factor of conditions was highly significant ($F(6,60) = 8{\cdot}406$, $P < 0{\cdot}0001$) and the interaction was not significant.

The occurrence of conceptual encoding effects can be investigated by determining whether response latencies for the congruent and incongruent colour word conditions differ significantly from the neutral condition, or each other. Neither of these colour word conditions differs significantly from the neutral condition, but the difference between them is significant (Scheffé test $F'(1,60) = 7{\cdot}7$, $P < 0{\cdot}01$). This difference could be due to encoding facilitation in the congruent condition, encoding interference in the incongruent condition, or both. Whichever is the case, however, it is evident that an effect at the conceptual encoding stage is present in this experiment.

The occurrence of effects at a response stage can be investigated by determining whether response latencies for the congruent and incongruent letter string conditions differ significantly from the neutral condition, or from each other. The incongruent letter string condition is significantly slower than the neutral condition (Scheffé test ($F'(1,60) = 20{\cdot}2$, $P < 0{\cdot}001$), but the congruent letter condition is not significantly different from the neutral condition. Both the congruent and incongruent letter string conditions differ significantly from the irrelevant letter string condition (Scheffé test $F'(1,60) = 4{\cdot}38$, $P < 0{\cdot}05$ and $F'(1,60) = 13{\cdot}64$, $P < 0{\cdot}001$ respectively).

Proportionally more errors were made in this task (3·6%), but this is not surprising given the complex nature of the task. Latencies for these were omitted from the analysis. Of the 55 errors made, 25 were wrong responses which had no systematic relation to the stimulus; 22 were naming of the letter assigned to the colour word distractor in the incongruent word condition; and eight of the errors were fast naming of the distractor letter in the incongruent letter condition.

Discussion

It is clear from the results in this experiment that response related distractors do cause interference, but this is only significant when these are also actual members of the response set. There is a congruency effect for response related distractors but no significant facilitation, although the difference between the congruent letters condition and the neutral condition lies in the right direction with 10 out of the 12 subjects giving faster mean RT's for the congruent condition. Stimulus related distractors also produce effects under these conditions, although it remains to be discovered whether these are interfering, facilitating or both. The potency of colour name distractors does not increase when they are also members of the stimulus set.

General discussion

Two points emerge from the results of these experiments. Firstly, any theory of the Stroop effect which assumes only a single locus for interference or facilitation is at best incomplete as both stimulus and response effects occur. Secondly, the stimulus and response effects differ in a way that may be of importance to theory. Stimulus related distractors cause equal amounts of interference whether or not they represent items in the stimulus set. Response related distrators cause more interference if they represent potential responses than if they represent items related to the response domain that do not occur as responses. Explanations of the two effects will have to be at least slightly different, since the two effects have slightly different properties.

Two loci for Stroop interference

These results give no reason to reject Seymour's account of the stimulus effect. The distractor and its hue each access their conceptual codes in semantic memory. A choice must be made between these two codes; that which was derived from the hue must be selected, and an appropriate response obtained for it. No one knows how this selection is made, but its difficulty varies directly with the semantic similarity of the two conceptual codes. The semantic similarity of the conceptual codes for two colours is unaffected by whether or not either of them appear as hues in the experiment. Thus the stimulus effect is just as large for colour names that do not occur as hues as for colour names that do. When the distractor and hue are identical, no choice between conceptual codes is necessary, since only one is accessed. Dual access to a single code might make that code available earlier; hence the congruity effect.

Can a similar account be given of the response effect? Such an account would suppose that when the distractor is a letter that differs from the letter associated with the stimulus hue, interference occurs because of the time required to choose between the conceptual codes of the two letters. This proposal is unattractive, because if it were correct all distractor letters that differ from the response letter should produce equal amounts of interference, which was not so.

We are thus led to consider some *other* locus for the response effect. Although differential priming effects do not seem to be involved in the stimulus effect, the response effect does seem to involve such priming. It is suggested that response effects arise in the system that is directly responsible for output of responses, the Logogen system (Morton, 1969) or the "output" Logogen system (Morton, in press). In this system, units that are used for output in a particular task are in a continual state of priming caused by repeated activation or by information from semantic memory. Thus distractors that are members of the response set provide evidence for units that are already activated to a certain extent, whereas distractors that are not members of the response set provide evidence for units that are not already activated. This "response set priming" makes distractors that are actual responses on some trials more potent in producing interference than distractors that are not.

The mode of action of response interference is still unclear, but it is suggested that either two output units are activated or two response programs become available and that interference constitutes the time taken to decide which unit or program is the appropriate one. Response facilitation may be the result of dual activation of the same output unit.

Resolution of Stroop interference

One difficulty remains for all theories of Stroop interference. How is the appropriate code/response selected? For conceptual encoding theory this problem lies in the processes involved in "disambiguation". For the Logogen theory this problem lies in the choice between two available responses. Three possible types of information could be used to resolve both types of conflict. One possibility is that subjects are able to selectively attend to the relevant stimulus aspect to some degree and thus attenuate the irrelevant information. The differential strength of the internal representations could then be used to resolve the conflict. A second possibility is that the source of the two conflicting types of information within the stimulus may be used; and a third possibility is that the speed of processing or time of arrival of the conflicting parts of the stimulus information could be used. All three types of information are potentially available during conceptual encoding, and the data presented here do not allow a choice to be made between them. Glaser and Dolt (1977) suggest that time of arrival is the information used to resolve conflict in the orthodox Stroop task. However, this requires the assumption that there is direct access from the encoding mechanism to the output mechanism which is now in doubt (Morton, in press). Source information is unlikely to be available to the output mechanism so it seems likely that strength of internal representation provides the basis for the decision as to which of the available responses is the appropriate one (Rabbitt and Rodgers, 1977).

Conclusion

The findings of the present experiments are that both stimulus related and response related distractors cause Stroop effects. Stimulus related distractors may cause interference or facilitation or both, although the results presented here do not distinguish between these possibilities. Response related distractors cause interference if they are identical to potential responses, and may facilitate response elicitation if they are identical to the correct response. Two loci of Stroop effects are proposed. Stimulus effects occur during conceptual encoding, response effects during response selection.

Throughout this paper it has been assumed that the transformation stage in transformation experiments is just an additional successive stage to the normal processing of Stroop stimuli. It may be argued that this additional stage changes the task sufficiently for more than orthodox Stroop interference to occur. However, there is no reason to reject the view that the transformation stage occurs after a single conceptual code has been obtained for transformation, nor any reason to believe that the transformation itself is affected by the presence of a code for another potential response.

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