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SELECTIVE ATTENTION TO WORDS AND COLOURS

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In the Stroop test it is found that the presence of words interferes with the task of naming colours. The usual account of this phenomenon is that the names of words are more readily obtained than are the names of colours and that the production of the latter is interfered with by the spontaneous occurrence of the former. Treisman and Fearnley (1969) have suggested a modification of the usual account such that stress is laid on the correspondence between the nature of the response ("verbal") and that feature of a stimulus which will dominate. The present experiments seem to demonstrate that the data which Treisman and Fearnley use in support of their claim can be attributed to the strategy which their subjects adopted in their task. Some further observations are made concerning the different levels at which comparisons can be made between two stimuli.

Introduction

In the Stroop Test (Stroop, 1935) subjects are presented with lists of colour-words which are printed in different colours. They are required (a) to read out the words while ignoring the colours in which they are printed (b) to name the colours while ignoring the words. Stroop found that the first task is almost as simple as reading out words printed in black. The second task, however, led to appreciably slower performance than a control condition in which the subject named colour patches. The most usual account of these data is that the more familiar and practiced reading response conflicts with the less familiar colour naming response either by virtue of a higher "habit strength" or by pre-empting the subject's attention. The implied differences between the ease of making the two responses is supported by Stroop's further finding that the time taken to read colour names printed in black ink is less than the time to name colour patches. More recent studies, summarized by Jensen and Rohwer (1966), have replicated these results with the Stroop Test and Morton (1969) has demonstrated analogous results where the subjects were required to sort cards into piles according to the number of objects on the cards when interference was found if the objects to be counted were digits or digit names. However, interference was also found if the objects were letters or words compared with control conditions where the objects were nonsense shapes or strings of *X*s. Morton accounted for these findings in the context of a general model for word recognition and verbal behaviour. A greatly simplified outline of this model is given in Figure 1. One feature of the model is that information proceeds from the stimulus analysers to the Logogen System, leading automatically to the production of an internal verbal response in the single channel prior to their manifestation as speech or use in mediating sorting responses. The various stimulus analysers are supposed to operate in parallel and will each give rise to an appropriate naming response. If multiple responses are available they will compete for entry into the single channel exit from the Logogen System. Thus, given that the identification of a word, letter or digit is faster than counting, we would expect to find the kind of interference which Morton reported due to the delay incurred in processing the counting response. Equally, since word identification is faster than colour naming, we would expect to find not only response competition of the kind found in the Stroop Test but also interference from any verbal material the colour of which was being named. This result was established by Klein (1964) who further showed that the amount of interference was directly proportional to such intrinsic factors as the meaning of the word. Thus it is not possible to attribute the interference to interactions at the level of the stimulus analysers, which, otherwise, might have been a plausible account.

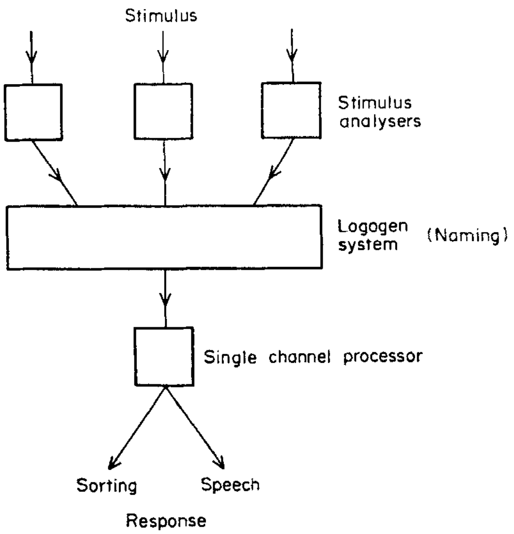

FIGURE 1

The above account differs from the usual ones (e.g. Klein, 1964) in specifying that the crucial variable is the relative speed of naming the various attributes of the stimuli. Thus, under appropriate experimental conditions the Stroop Effect can be reversed, as was shown by Gumenik and Glass (1970). They required their subjects to read colour names or name colours which were seen through a mask. In this condition reading the words took longer than naming the colours. As we would expect, when the stimuli were coloured colour-words the colours interfered more with reading than did the words with colour naming.

Treisman and Fearnley (1969) have recently challenged the traditional account of the Stroop Test. They suggested that one possible explanation of Stroop's results lay in the "mismatch between stimulus attribute and response". In the

Stroop Test, subjects are required to produce words in response to colours in one case and in response to words in the other. Treisman and Fearnley suggest that "If it were possible for subjects to generate colours, the reverse result might be obtained, that is, the 'colour' response might be more difficult to the stimulus of words than to the stimulus of colours". A more extended explanation they suggested was that "interference with selective attention or response might arise only when the irrelevant stimulus attribute belongs to the same class as the response". They tested these and the traditional explanations with an ingenious experiment which involved subjects sorting cards into two piles depending on whether they were the same or different by various criteria. They used three packs of cards, each card having two items on it. In pack A there were two colour words written in upper case with a felt pen: the top word was written in colour and the lower one in black. For pack B there was one coloured word and a row of four coloured *X*s below. Pack C had a black word and a row of coloured *X*s. These three packs were sorted in five different ways, the arrangement of words and colours being such that, by the criteria used, half the cards required a "same" response and half a "different" response. The five conditions are described below. We have added a symbolic representation of the task in which a subscript represents a source of interference.

A(i) W_c/W —match the top word to the bottom word ignoring the top colour.
A(ii) C_w/W —match the colour of the top word to the bottom word ignoring the nature of the word at the top.
B(i) C_w/C —match the two colours ignoring the word at the top.
B(ii) W_c/C —match the word at the top with the colour at the bottom ignoring the top colour.
C W/C —match the word at the top to the colour at the bottom (with no interference).

The A(i) and B(i) conditions should be faster than either A(ii) or B(ii) since the comparisons required in the former can be performed on the basis of the sensory attributes directly, without having to name the stimuli (cf. Posner and Mitchell, 1967; Posner, Boies, Eichelman and Taylor, 1969). The C condition would have the advantage over A(ii) and B(ii) of there being no interfering attributes. The crucial comparison is between packs A(ii) and B(ii). In both of these packs the subject is being asked to match a word with a colour. In the former case the interfering aspect of the stimulus is a word; for the latter it is a colour. On the usual account of the Stroop effect we would expect A(ii) to take longer than B(ii) since words are supposed to be more rapidly recognized (or more difficult to ignore) than colours, and would interfere more with the colour-word match. Treisman and Fearnley on the other hand, in extending their account of the Stroop effect, predict no difference between the A(ii) and B(ii) packs.

The data reported by Treisman and Fearnley (henceforth referred to as T & F) is given in the first line of Table I. They found that A(ii) and B(ii) were slower than the other packs but found no difference in the time between these two conditions. They conclude that this is due to "interference from a competing value within one attribute when one is matching across attributes" and, by analogy,

TABLE I

Results of Treisman and Fearnley (1969) compared with the present Experiment I

	Subjects	A(i)	B(i)	C	A(ii)	(Bii)
		W_c / W	C_w / C	W / C	C_w / W	W_c / C
Treisman and Fearnley	32 Undergraduates	60·5	58·8	71·3	81·4	78·2
Morton and Chambers	10 Housewives	42·0	39·4	49·4	98·6	61·1

suggest that "the interference in the Stroop test is nothing to do with either the greater familiarity of the reading response to words than the naming response to colours, or any inherently greater distraction from words in selective attention to colours than from colours in selective attention to words". As such conclusions were contrary to our own theoretical position we decided to replicate the T & F experiment prior to exploring the situation more deeply, with the intent of attempting to reconcile the two positions.

Experiment I

Method

Materials

The packs of cards used in the five conditions—A(i), B(i), C, A(ii) and B(ii)—were each composed of 48 cards as described by T & F. There were 24 "same" cards and 24 "different" cards in each pack, four in each colour. The words and coloured *X*s were hand-written with felt-tipped pens in the same six colours used by T & F (blue, red, brown, orange, purple and green) on white cards $2\frac{3}{8} \times 3\frac{5}{8}$in.

Design

Each subject sorted the packs according to a Latin square order and then sorted the packs in reverse order, e.g. 12345, 54321, as with T & F. We differed from the latter in that we gave subjects a practice trial before each main trial. Only the main trials were analysed. We found this procedure necessary as attempts to mimic the T & F design exactly led to enormous interference from one condition to the next. Thus, in the practice trials an average of 3·25 errors were made compared with an average of 0·97 errors in the main trials.

Procedure

Ten paid housewives from the APU Subject Panel were tested individually by one experimenter. Subjects were instructed to sort the cards into two piles, according to whether they were the "same" or "different" by the particular classification. They were told that where there was a word written in a colour they would be asked either what the *word* "said", or what *colour* ink the word was written in. For pack A(ii) the instruction would be "Match the colour of the top word to the word at the bottom". Four demonstration cards were used before each trial. The E read these four cards aloud always beginning at the top line e.g. in pack A(ii) "*colour* 'blue' *word* 'blue', the same". The subject then took up the pile and began sorting "as quickly as possible without making errors". Timing began when the first card hit the desk. At the end of each practice trial the errors were counted and the subject read aloud the error cards correctly before the main trial was begun under that condition.

Results

The mean reaction times of the two main trials for each pack are shown in Table I and can be compared with those of T & F. The same order of difficulty for sorting the packs was observed but unlike the T & F results, the A(ii) pack was significantly slower than the B(ii) pack ($P<0{\cdot}01$ using a Wilcoxon test.) In fact all subjects took longer to sort the A(ii) pack than the other packs. There was no significant difference between the A(i) and B(i) packs; performance on these two packs was faster than that on the other three for all subjects with the exception of one for whom C was faster than A(i); the C pack was easier than A(ii) and B(ii) for all subjects.

We are faced with the problem of accounting for the discrepancy between the two experiments with regard to the relative performance on the A(ii) and B(ii) packs. The most obvious difference between the two experiments was in the subjects used. In exploratory experiments a few subjects mentioned that they found the task of sorting the A(ii) pack much easier if they read the *word* on the bottom line before the *colour* on the top line. It seemed easier to match a known *word* to a colour than to ignore an irrelevant word and look at what *colour* ink it was written in and then match it to the word below. If this were the case, then it seemed probable that the housewives were following the instruction to read down the card, whereas the undergraduates used by T & F were choosing the easier method. We decided to test this hypothesis by instructing subjects more explicitly to use certain strategies.

Experiment II

Method

Sixteen housewives sorted packs A(ii) and B(ii) only, starting either at the top, i.e. as in Experiment I, or at the bottom (b) line. Subjects were instructed as follows:

A(ii): "read the *colour* on the top line and match it with the *word* below".

A(ii)b: "read the *word* on the bottom line and match it with the *colour* above".

B(ii): "read the *word* on the top line and match it to the *colour* of the *X*s below".

B(ii)b: "read the *colour* of the *X*s on the bottom line and match it to the *word* on the top line".

These explicit instructions contrasted with the equivalent implicit directions in Experiment I. In all other respects the method was the same as in Experiment I.

Results

The mean reaction times for the four packs are shown in Table II. There was no significant difference between A(ii)b and B(ii)b but all other comparisons were significant by the Wilcoxon Test ($P<0{\cdot}01$). As in Experiment I all subjects were slower on A(ii) than on B(ii). Thus it seems as though we can reproduce either the T & F results or our own by changing the instructions given to the subjects.

TABLE II

Results of Experiments II and III

	A(ii)	A(ii)b	B(ii)	B(ii)b
II	C_w / W	C_w / W	W_c / C	W_c / C
	100·4	81·3	66·9	75·6
	A(ii)	A(ii)R	B(ii)	B(ii)R
III	C_w / W	W / C_w	W_c / C	C / W_c
	69·8	59·3	47·4	50·3

Another way of finding out whether the starting point of the task makes a difference, is to reverse the stimuli on the cards so that, for example, in a modification of the A(ii) pack, a black *word* on the top line is matched with the *colour* ink in which the word below is written. This was tested in the following experiment.

Experiment III

Method

Eight RN ratings and eight housewives sorted packs A(ii), A(ii)R, B(ii) and B(ii)R, the difference between the normal and the R packs being that for the normal packs the stimuli were written in the normal order with the coloured word at the top, and for the R pack the stimuli on the top and bottom lines were reversed. The subjects were instructed to read the top line (*colour* or *word*) first and then to match it with the *word* or *colour* below according to the particular classification. Otherwise the method of Experiment I was followed.

Results

The mean reaction times for the 16 subjects are shown in Table II. The same order of difficulty of sorting the packs is evident. Pack A(ii) was sorted significantly slower than all other packs ($P<0{\cdot}01$, Wilcoxon) and, as in the previous experiments, the difference between this pack and B(ii) was shown by all subjects. In this experiment the difference between A(ii)R and B(ii)R was significant, 14 out of the 16 subjects being faster for B(ii)R.

Discussion

The situation we are primarily concerned with is the case where subjects are comparing a colour-word with a colour, with the interfering stimulus being either a colour-word or a colour. T & F failed to find any difference between these conditions. We, on the other hand, have demonstrated a difference in that when the interfering stimulus was a colour-word all 42 of our subjects, in three experiments, performed the task more slowly than when the interfering stimulus was a colour, as would be expected by our own account of the Stroop phenomenon. Furthermore we were able to abolish the difference between the effects of the two kinds of interfering stimulus by instruction (Experiment II) and severely reduce it by changing the positions of the items on the stimulus cards (Experiment III). Thus we believe that it is possible to account for T & F's results by supposing that their subjects, undergraduates, discovered that the interfering effects of the words in the A(ii) pack could be reduced by adopting a particular scanning strategy. Dyer (1971), who measured reaction times to individual cards, and replicated T & F's results, explicitly comments that he did not control the subject's fixation patterns. Thus his subjects too could have adopted the most favourable strategy.

We can suppose that the subjects in our task have basically two ways of operating. The most obvious one is that they name, or derive a semantic coding for the two aspects of the stimulus which have to be compared and then check whether or not the two names or codes are the same. In terms of the grossly oversimplified model in Figure 1, this operation would be performed at the level of the processor. The naming operation need not, of course, be overt. In the original Stroop test we have the naming operation without the comparison, and the results of that test and the experiments of Klein (1964) and Morton (1969) referred to in the Introduction indicate that when a subject is trying to analyse and name one feature of a stimulus the presence of other features interferes. The simplest way of conceptualizing this situation is to suggest that all the stimulus analysers operate simultaneously with the result that the appropriate name of an irrelevant attribute enters the processor and blocks, or interferes with the naming of the relevant attribute. As was indicated in the Introduction, the evidence that printed words are more rapidly named than colours is then sufficient to account for the Stroop phenomena. It would also account for the differences found in the present experiments between the A(ii) and B(ii) packs, the irrelevant word in the A(ii) pack interfering more than the irrelevant colour in the B(ii) pack with the colour-word match.

The second possible method of comparing two values of a stimulus is in terms of the physical properties of one of them. Posner and his associates (Posner and Mitchell, 1967; Posner *et al.*, 1969) have provided evidence that such physical matching is faster than name matching at least for the case where the two features have the same attributes. In addition, since such a match does not involve the processor in Figure 1, the presence of an interfering value in a different attribute could not affect the matching process in the same way that we suggest it interferes with a name match. This expectation agrees with a result by Egeth, Blecker and Kamlet (1969). As these authors used a different paradigm and were only concerned with the effects of words on a colour-colour match we performed Experiment IV.

Experiment IV

Materials

The following six packs of cards were used.

E C/C —two rows of coloured *X*s to be matched by colour.

B(i) C_w/C —the colour of a colour word had to be matched to the colour of a row of *X*s. This pack was used in Experiment I.

D W/W —two printed black colour-words had to be matched.

A(i) W_c/W —two words to be matched, the topmost of which was printed in colour. This pack was used in Experiment I.

D′ W/w —this resembled pack D except that the lower word was written in cursive script.

A′(i) W_c/w —this resembled A(i) except that the lower word was written in script.

A comparison of performance on E and B(i) will indicate the extent to which the presence of a word interferes with a colour-colour match; a comparison of D and A(i) will show whether colour interferes with a word-word match. Pack D′ was designed to indicate that pack D does involve a physical match. With D′, although both the stimuli are words, the subject cannot make a simple physical match since the stimuli are not physically identical.

Method

Twelve housewives sorted the six packs of cards according to a Latin square design. The method was otherwise identical to that used in the other experiments.

Results and discussion

The mean sorting times for the 12 subjects are shown in Table III.

The difference between D and B(i) is not significant, and that between A′(i) and D′ is only significant with $P = 0{\cdot}05$ by the Wilcoxon test with two of the 12 subjects going the wrong way. All other differences are significant with $P < 0{\cdot}01$, ($t = 6{\cdot}5$ for D′ vs A; $t = 7$ for B; vs E; $t = 0$ for all other comparisons). These data show that it is easier to manipulate colours than words at the level of the sensory analysers. In addition the difference between D and D′ reinforces the belief that words can be matched with each other at the sensory level. Finally it is clear that even when comparisons are being made at the sensory level there is nonetheless interference from irrelevant stimuli. This could be accounted for by supposing that the irrelevant stimulus is named and the covert naming response interferes at the level of the processor with the classification response in the same way that a letter interferes with a counting response (Morton, 1969). Alternatively, it might be that the interference takes place at the level of the sensory analysers, the (autonomous) activity of one attribute analyser or the effort to exclude the irrelevant information reducing the efficiency of the physical comparison within the relevant attribute. We cannot decide between these alternatives on the present evidence, but all of them imply underlying processes of a complexity beyond the scope of the present discussion.

TABLE III

Results of Experiment IV

E	B(i)	D	A(i)	D′	A′(i)
C	C_w	W	W_c	W	W_c
C	C	W	W	w	w
25·8	27·2	27·7	31·0	33·3	35·2

General Discussion

We had supposed that a within-attribute match would be unaffected by the presence of information in another attribute. The data of Experiment IV showed this supposition to be untrue, counter to the finding of Egeth *et al.* (1969). One difference between the latter's experiment and ours was that they presented six conditions in all of which the subjects had to process colours and ignore words. In our Experiment IV, on the other hand, our subjects had to compare words in four of the six conditions. There is a strong possibility that Egeth's subjects could develop strategies which cut down on the input of information concerning the words sufficiently to enable them to resist interference when colour-words were used with a same–different response, although, as Egeth *et al.* showed, not sufficiently to resist interference when colour-words were used in a colour naming task or when the words "same" and "different" were used in a same–different task. Our subjects had to switch between colour matching and word matching and so would have less opportunity to develop appropriate defensive strategies.

In spite of this it is clear that the within-attribute match is less subject to interference than the across-attribute match. In Experiment I the effect of an interfering colour on a word-colour match was, on average, 11·7 s (B(ii) vs. C). The average effect of an interfering colour on a word-match (A(i) vs. D, Experiment IV) was only 3·3 s. The difference between these comparisons is highly significant, there being no overlap between the distributions. The same is true regarding the effect of an interfering word on a colour-colour match (B(i) vs. E) compared with its effect on a word-colour match (C vs. A(ii)).

It follows that it would be advantageous for the subjects if the word-colour match could be converted to a within-attribute match. This could be done effectively if the subject first read the word and then either generated an internal code or set appropriate stimulus filters against which to match the colour of the coloured word. The interfering word would then have less chance of affecting the judgement. We suggest that this is the strategy which T & F's subjects adopted spontaneously and which our subjects were led to by instruction in Experiments II and III. We presume that our subjects otherwise used a name match with the A(ii) pack in which case interference would be greater.

Somewhat similar results to these have been shown by Seymour (1969, 1970). Seymour's subjects were required to make a same–different judgement between one of the words "square" and "circle" and one of the corresponding shapes. He showed that responses were faster when the word was presented first and suggests that "a word-shape comparison typically proceeds via visual analysis of the word to the formation of some representation which can be used in direct tests for congruence on incoming data defining the characteristics of the shape" (Seymour, 1907, p.445). One difficulty with using Seymour's data to support our position is that he only found an advantage for the word-shape match over the shape-word match when his subjects were uncertain as to the order of presentation of the items. In our experiments, however, the format of the cards was fixed for any one pack.

It remains to explain why performance on the B(ii) pack cannot be helped in the same way. In fact, in both Experiments II and III the instructions which helped the A(ii) pack made performance on the B(ii) pack worse. ($t = 10$, $P < 0{\cdot}01$ in Experiment IV, $t = 27$, $P < 0{\cdot}05$ in Experiment III, two-tailed Wilcoxon). A sufficient reason for this difference could lie in the relative stimulus complexity of a colour on the one hand and a colour word on the other. Thus, it is plausible to suppose that the stimulus analysers can be set fairly rapidly to select a colour (although the relevant experiment does not appear to have been done). The work of Posner *et al.* (1969) however, showed that it took about 750 ms for subjects to generate an internal image of a single letter. Even without the further assumption that the generation of a whole word would take longer, this time would be prohibitive considering that the mean times for the B(ii) pack in the first three experiments only ranged from about 1·0 to 1·4 s. Our assumption concerning the relative ease of handling colours at the stimulus level (as opposed to naming, for which words are faster) is supported by the superior performance in colour matching compared with word matching in Experiment IV (E vs. D). In addition it is supported by the results of an experiment by Lund (1927) who showed that subjects could note the occurrences of a specified colour in a matrix of other colours about twice as quickly as they could count the occurrence of a specified colour name among other colour names. In Lund's experiment there were no interfering values, but Uleman and Reeves (1971) have shown that with a set of coloured words it is still easier to note the occurrences of a specific colour (ignoring the words) than to note the occurrences of a specific colour-word (ignoring the colours). This result appears to contradict the basic Stroop result but is entirely explicable if one assumes that the scanning task primarily involves setting the stimulus analysers and using the naming mechanism only when the appropriate stimulus value has been detected.

To summarize, our position is that, in a task which involves the naming of one value of a stimulus, the presence of another stimulus value in a different attribute will interfere in proportion to the relative speeds of naming the attributes. In part this is a function of the kind of attribute being named. Thus as we have indicated, under usual conditions reading is faster than colour naming or counting. Shor (1970) has found related results, using a task where he required subjects to name the directions in which arrows were pointing. This task took longer than reading the words *left, right, up* and *down*, and in a display where the words were located inside arrows the interference affected arrow naming and not reading. It was noted in the Introduction that not all verbal stimuli interfere to the same extent with colour naming. The evidence is that the amount of interference is a monotonic function of the ease of recognition of the words. This is partly influenced by the experimental conditions, in that words associated with the response names interfere more when the association is greater (Morton, 1969; Klein, 1964; Scheibe, Shaver and Carrier, 1967). In addition, words of high frequency of occurrence in the language, which are recognized more easily, interfere with colour naming more than do low frequency words (Klein, 1964), and three-letter groups interfere as a function of their pronounceability, a variable which is known to affect recognition (Bakan and Alperson 1967). Since such variables cannot by definition, operate prior to the naming system the simplest hypothesis, consistent with all the evidence, is that the interference occurs after naming (Morton, 1969; Dalrymple-Alford and Azkoul, in press). In terms of the model in Figure 1, this would be in the processor.

Finally it is apparent that within-attribute matches are more resistant to interference than between-attribute matches. As a consequence it can be advantageous for subjects to adopt a strategy of converting a between-attribute match into a within-attribute match by using one attribute to modify the stimulus analysers relevant to the other attribute. The advantages of adopting this strategy will be a function of the complexity of the second of the two attributes.

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