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CATEGORIES OF INTERFERENCE: VERBAL MEDIATION AND CONFLICT IN CARD SORTING

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When subjects sort cards by the number of symbols on the cards, the nature of the symbols interferes with the sorting in ways which are similar to those shown by Klein (1964) using a variant of the Stroop test. When the symbols have names, such as letters and words, there is a decrement in performance; when the symbols are digits the decrement is increased. These and related results form the basis of a functional model in which different types of interference between stimuli can be enumerated, and those operating in the sorting task isolated.

The features of the final model are: (1) sorting proceeds via a verbal mediation; (2) the process of recognition of familiar named symbols is autonomous and results in the availability of the name of the symbol; (3) this name enters the same store as the mediating response and so can delay it; (4) in the present range of tasks there is no interference prior to the availability of the symbol name; (5) learning to reduce interference does result in a change prior to this stage; (6) the interference effects are analogous to word recognition phenomena.

The Stroop Test (Stroop, 1935) is the classical example of a task involving conflicting responses which arise from different properties of a stimulus. In this test, colour names are printed in different colours, the subject is required to name the colour of the ink, and he becomes confused between the word itself and the colour in which it is printed. Klein (1964) has suggested that the interference arises from competition between a motor response aroused from the word and the 'semantic field' associated with the colour names. When looked at in terms of current theories of information processing, Klein's explanation is insufficient because it is ambiguous. The series of short experiments described here explore a situation analogous to the Stroop test; the task is that of sorting cards and the primary conflict is between the number of symbols on a card and the name of the symbol.

The main aim of this paper is to develop as rigorously as possible a functional description of the processes involved in this task and in the Stroop test, i.e. to describe the nature of interference. The style of the analysis and description is that used in general by Broadbent (1958), in particular by Treisman (1960) and by Morton (1964*a*, *b*; 1969). In model-making of this kind, two evaluation criteria are used. First, *ceteris paribus*, the more economical of two alternatives is to be preferred, where 'economy' is to be judged by the number of pathways and functional units. Secondly, where a new construct has to be introduced to explain some data, it is preferable to introduce one which has already been suggested as an explanation of other data provided that (*a*) the combined model still encompasses the latter set of data, and (*b*) the amount or variety of new data encompassed compensates for the added complexity of the system.

The experimental results which follow are largely intuitively obvious and should be regarded as either demonstrating the basic data or eliminating logical alternatives to the developed system within the context of the theoretical method employed. The latter qualification means, for example, that we do not consider alternative models phrased in general information theory terms. Rabbitt (1964, 1967) uses such a form

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of analysis in considering the specific case of card-sorting experiments where irrelevant information has to be ignored, linking his results to a variety of other work concerned with the effects of varying stimulus and response entropy. Garner (1962), on the other hand, uses concepts of structure, associated mathematically with information theory but different from it conceptually, to provide a logical analysis of several kinds of psychological problem including some to which the present problem is related. Such approaches as these are not considered to be alternative models to the one put forward; they represent alternative *types* of theory. This paper is not concerned with evaluating these various approaches; each has its heuristic value and none is likely to be, in any ultimate sense, 'correct'. The problem of mapping the various approaches on to one another is postponed for a later paper. (An analogous situation has recently arisen in the study of the psychology of language, where many workers have abandoned the informational forms of analysis previously used in favour of ones based on transformational generative grammars (Miller & Chomsky, 1963). This does not mean that, for example, notions of probability can have no place in models of language behaviour (Osgood, 1963; Morton, 1964*c*). It may, however, be more profitable to develop one type of conceptual system more fully before attempting a liaison, and such is the present approach.)

The basic problem with the Stroop test, and the present task, is to describe the nature of the interference, i.e. to pinpoint, within a functional model which uses the conventions of black boxes and flow diagrams, the location of the interference with respect to the isolable processes hypothesized. The technique used to elucidate the problem is described below.

METHOD

The task involves sorting a pack of 36 cards into six equal piles according to the number of symbols, from one to six, on the cards. The cards to be sorted were 6 × 9 cm and the symbols were typed. The cards had to be sorted into six boxes, 10 cm wide, which were labelled 1 to 6 from left to right. The subjects, R.N. ratings aged 18–25, were instructed to 'sort the cards as quickly as possible according to the number of symbols on the cards without making errors'. In all cases they were shown two or three of the cards and it was verified that they understood the instructions. No further instructions were given regarding errors. Unless otherwise stated the symbols were arranged in regular patterns identical for all cards with a particular number of symbols. The 'counting' could thus be regarded as a form of pattern recognition.

In nearly all the experiments a *trial* is defined as a sequence of from two to four sortings. Usually the order of sorting packs within a trial was not counterbalanced but was in such an order that any practice effects would act against the hypothesis under test. In all experiments there was a general practice effect (cf. Table 1). In Expt. VIII the practice effect outweighed the factor under test; reversing the order of sorting for a second group yielded a significant result. Thus the method generally used provides a most stringent test of the hypotheses investigated. In no experiment are points of interpretation affected by the method. For the convenience of the reader the experimental results are summarized in Table 6. Details of the two statistical tests used, the Wilcoxon and the Mann–Whitney, may be found in Siegel (1956).

Experiment I ($n = 18$): *The effects of letters and digits*

This experiment tested the hypothesis that symbols with names would be more difficult to sort for numerosity than symbols without names. Eighteen subjects first sorted a pack upon which were typed 'shapes' made up from the typewriter (*, ⅅ, *ƒ*, :̲, (̲ and ″). They did this twice to reduce the practice effects noted in preliminary experiments. They then had three trials, in each of which they successively sorted packs with shapes (S), letters (L) and digits (D) in that order. For all three packs the symbols on any one card were the same. The letters used were A–F, and the digits 1–6; all possible combinations of symbol and number occurred once in a pack. Examples of the cards are shown in Fig. 1(*a–c*).

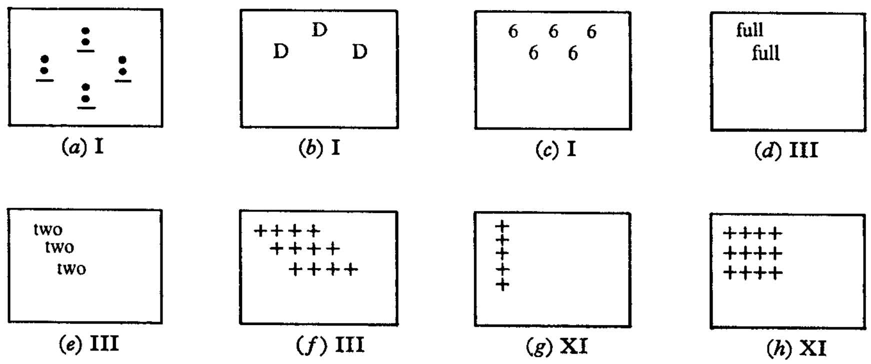

Fig. 1. Examples of the cards used. The Roman numerals refer to the experiments in which the cards were used.

Results

1. There was a large practice effect in sorting up to the third trial.

2. There was an initial slowing effect of nameable symbols; both letters and digits.

3. The decrement due to the letter symbols vanished after the first trial. This, however, is confounded with the general practice effect. The difference between L and S was less on the second ($P < 0{\cdot}01$) and third ($P < 0{\cdot}025$) trials by the Wilcoxon test. This is not confounded by the practice effect since any non-linearity in the general practice curve (i.e. a progressive reduction from trial to trial in the size of the practice effect) would tend to *reduce* the difference between the packs on the first trial more than on the second and third trials. So we can conclude that some learning has taken place which has the effect of reducing the amount of interference brought about by the letters.

4. A difference between the digit pack and the other two packs remained on the third trial in spite of the within-trial practice. The absolute difference in times between S and D was less on the second and third trials than on the first ($P < 0{\cdot}025$ in both cases); again we can conclude that there is some learning.

5. There was no significant change in the difference between L and D between the trials. Thus we can tentatively conclude that, whatever the nature of what is learned, it acts equally to reduce the amount of interference brought about by both letters and digits.

Experiment II ($n = 18$)*: The effects of pattern irregularity*

Expt. I was replicated with one difference. Instead of the symbols being typed in regular patterns, they were written in irregular patterns so that each card had to be studied more carefully in order to count the symbols rather than just recognizing their pattern. The mean times are given in Table 2.

Table 1. *Experiment I* (n = *18*)*: regular patterns, mean times in seconds*

	Shapes (S)	Letters (L)	Digits (D)	
Practice				
1	62·1	—	—	$P_1 > P_2 > S_1$ ($P < 0·005$)
2	52·8	—	—	—
Trial				
1	50·3	52·6	54·1	$D > L > S$ ($P < 0·025$); $D > S$ ($P < 0·005$)
2	49·6	47·9	50·8	$D > L$ ($P < 0·005$)
3	47·9	48·2	49·5	$D > L$ ($P < 0·025$); $D > S$ ($P < 0·01$)
	$S_2 > S_3$ ($P < 0·025$)	$L_1 > L_2 > L_3$ ($P < 0·005$)	$D_1 > D_2$ ($P < 0·025$)	—
	$S_1 > S_3$ ($P < 0·005$)	—	$D_1 > D_3$ ($P < 0·005$)	—

Table 2. *Experiment II* (n = *12*)*: irregular patterns, mean times in seconds*

	Shapes (S)	Letters (L)	Digits (D)	
Practice				
1	62·0	—	—	—
2	60·3	—	—	—
Trial				
1	56·3	60·0	63·4	$L > S$ ($P < 0·025$); $D > L$ ($P < 0·01$); $D > S$ ($P < 0·005$)
2	55·3	56·7	61·9	$D > L, S$ ($P < 0·005$)
3	53·9	56·3	58·3	$L, D > S$ ($P < 0·005$)
	$S_1 > S_3$ ($P < 0·01$)	$L_1 > L_2, L_3$ ($P < 0·025$)	$D_1, D_2 > D_3$ ($P < 0·005$)	—
	$S_2 > S_3$ ($P < 0·025$)	—	—	—

(Significance was tested using the Wilcoxon test.)

Results

1. All the sorting times were significantly longer than in Expt. I (using the Mann–Whitney test). The P values are given in Table 3. Such differences are to be expected from the nature of the tasks.

2. The effect of letters persists within the design to the third trial, though it is always less than that due to digits.

3. The difference between D and S was less on the third trial than on the first two ($P < 0{\cdot}025$ in both cases). There were no significant changes in the differences between S and L or D and L.

Table 3. *Significance* (P *values*) *of differences in sorting times between Experiments I and II by the Mann–Whitney test*

	Trial		
	1	2	3
Pack S	0·001	0·05	0·01
L	0·05	0·01	0·001
D	0·025	0·001	0·01

Table 4. *Experiment I v. II; differences between packs*

	Total		
	1	2	3
Difference $L-S$	n.s.	0·025	0·001
$D-L$	n.s.	n.s.	n.s.
$D-S$	n.s.	0·001	0·025

The significance levels indicate that the appropriate difference was greater in Expt. II than in Expt. I.

4. The differences between the packs on each trial in Expt. II were compared with the equivalent differences in Expt. I, using the Mann–Whitney test. The significance levels for the comparisons are given in Table 4. On the first trial the effects of both letters and digits were the same in both experiments, i.e. the difference between the layout of the symbols of the cards in the two packs had a general effect. On the second and third trials, however, the difference between the S and the other two packs was less in Expt. I than in Expt. II, whereas the (D–L) differential remained the same. These data are completely consistent with the statistics quoted above and lead to the conclusion that whatever is learned which results in the reduction of the interference can be applied more effectively under the conditions of Expt. I than Expt. II.

Summary of results of Experiments I and II

1. The presence of nameable symbols increases the sorting time.
2. The slowing effect of letters is smaller than that of digits.
3. The more detailed the inspection necessary, forcing the subject to count rather than rely on pattern recognition, the longer the sorting times.
4. On the first trial the decrement due to the symbols is the same in the two experiments regardless of 3.

5. There is a general practice effect which applies to all the packs used.

6. There is a learning effect, whereby the interference of the symbols is reduced, which appears to apply equally to letters and digits in Expt. I and, if anything, more to the digits in Expt. II. Overall this learning is greater in Expt. I than in Expt. II.

Experiment III ($n = 11$): *The effect of words*

The main interference result is not dependent upon using Arabic numerals as visual stimuli. It might be argued that the greater effect of digits in the previous experiments was due specifically to the presence of Arabic numerals as labels on the sorting boxes. The following experiment, using words, disproves this hypothesis. Four packs of cards were prepared, each with a string of letters repeated on one to six lines. In the experimental pack (E) the strings made up the digit names 'one' to 'six'. In the word pack (W) the words 'white', 'low', 'easy', 'full', 'his' and 'big'

Table 5. *Mean times in seconds*

(a) *Experiment III* ($n = 11$)*: words* (W) *v. digit names* (E)

P_1	P_2	P_3	W	E	
61·6	53·8	50·5	52·4	55·5	$P_1 > P_2 > P_3 < W,E$ ($P < 0·005$); $W > E$ ($P < 0·01$)

(b) *Experiment IV* ($n = 10$)*: position sorting*

C_1	C_2	E_1	E_2	
43·6	39·9	41·0	43·0	$C_2 < C_1, E_2$ ($P < 0·005$); $E_1 < E_2$ ($P < 0·01$)

(c) *Experiment VII* ($n = 12$)*:* 7, 8, 9 *v.* 3, 4, 5

	S	D_7	D_3	
Trial 1	48·6	50·8	54·3	$S, D_7 < D_3$ ($P < 0·005$); $S < D_7$ ($P < 0·025$)
Trial 2	47·4	48·3	50·2	$S < D_3$ ($P < 0·005$)

(d) *Experiment VIII* ($n = 24$)*:* 7, 8, 9 *v.* J, K, L

	S	L_J	D_7	
Group I ($n = 12$)	49·6	51·8	51·3	$S < D$ ($P < 0·005$); $S < L$ ($P < 0·01$)
	S	D_7	L_J	
Group II ($n = 12$)	48·0	51·5	46·3	$S < D$ ($P < 0·005$); $S < L$, ($P < 0·025$)
	Pooling the groups			$L < D$ ($P < 0·025$); $S < D$ ($P < 0·005$); $S < L$ ($P < 0·01$)

were used, these being words of the same length as the digits and of a higher mean frequency of occurrence in the language. The practice pack (P) contained strings of crosses of the same lengths as the words in the other packs. Examples are shown in Fig. 1(*d–f*). Subjects sorted the P pack twice and then had one trial of P, W and E. The instructions were to sort the cards by the number of rows. Mean times are given in Table 5(*a*). The differences in sorting times are of the same order as those in the previous experiments.

Experiment IV ($n = 10$): *Position sorting*

The same kind of phenomenon can also be shown when the sorting task is dependent upon the position of a word on the card. The words were at the top of the cards, at the right edge, in the centre or at the left edge. The first experimental pack (E_1) used the words 'white', 'black' and 'grey', the second one (E_2) the words 'left', 'right' and 'centre'. All combinations of word and position were equally represented.

Subjects sorted a control pack *C* (where strings of crosses were the stimuli) twice, and then the two experimental packs. The mean times are given in Table 5(*b*). Only one subject sorted *E* faster than *C*; there were no other reversals.

Two kinds of interference

When subjects are performing the task they invariably move their lips and sometimes actually call out loud the numbers corresponding to the sorting categories. If anything, this procedure becomes more marked as the subjects become more practised. It is reasonable to suppose, then, that the sorting response is normally mediated by the digit name corresponding to the numerosity, by means of either an overt or a subvocal response. The increase in sorting time when the symbols were digits may most readily be explained, then, by assuming that the digits mediate incorrect sorting responses which conflict with the sorting responses to the number of symbols. Such a process is represented in Fig. 2. The hypothesis is strengthened by the observation that even when subjects did not actually mis-sort a card, they frequently made intention movements towards the pile corresponding to the digit before correcting themselves and sorting for the numerosity. This phenomenon persisted up to the third trial in Expts. I and II.

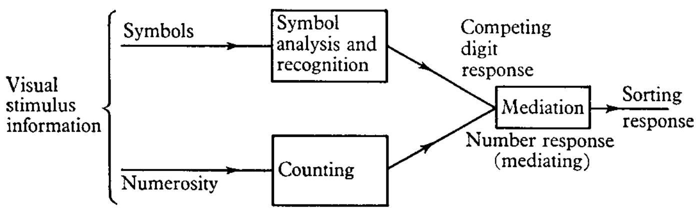

Fig. 2. The simplest model for digit–number interference.

The interference effects of letters and words, however, require that some more detailed model of the situation be formed if a consistent explanation is to be found, since there are no sorting responses appropriate to such stimuli. (The objection that *A* is closely associated with—is 'compatible' with—*1* can be countered by the lack of such correspondence within the word pack in Expt. III or in the E_1 pack in Expt. IV. Thus we still lack a generalizable model.) There must therefore also be some other kind of interference prior to the mediation. The stage preceding the mediation is concerned with producing the vocal or subvocal mediating responses and we can then most simply suggest that the mediating response is interfered with by any other subvocal response, such as a symbol name. If the symbol were a digit, one would also expect a competing sorting response to be mediated as previously indicated. These processes are depicted in Fig. 3. In this model, when any symbol is recognized there is interference through the channel *DL*; digits may additionally mediate an incorrect response through channel *D*, giving rise to an additional decrement in the sorting time.

At this stage we can eliminate two other possible classes of explanation of the results: that the interference is related either to the common sensory modality of the primary (numerosity) and interfering aspects of the task, or more specifically to the

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fact that both aspects of the task were visual. The first possibility is that the interference might be due to the stimulus masking of relevant information by the irrelevant information. Such a hypothesis will not hold in the present experiments, since the symbols themselves were of equal visual complexity on all compared packs. Secondly, it might be suggested that the interference is within a part of the system which deals with visual stimulation only, performing the tasks both of counting and of processing the shape information. While this explanation cannot be disproved it can be shown to be insufficient, as far as the general phenomena are concerned, by the following experiments which demonstrate auditory interference with the visually based sorting task, and with an auditorily based counting task.

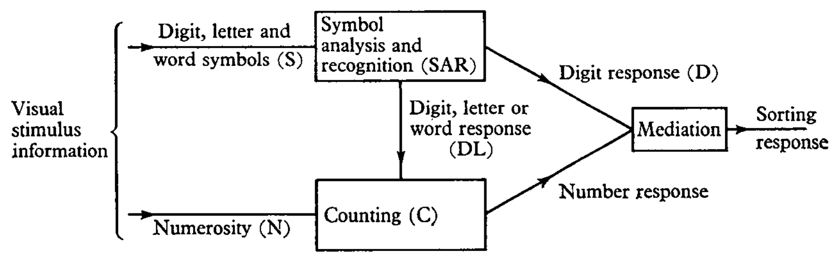

Fig. 3. A model which allows two kinds of interference.

Experiment V: Auditory interference with visually based task

In this experiment, which will be reported more fully elsewhere, subjects sorted the *S* pack. In the experimental conditions the experimenter spoke words at a rate of about 2 per sec. Subjects were instructed to ignore these words. In the first case the words were drawn at random from the set 'low', 'full', 'his', 'big', 'white' and 'black'; in the second case the words were the digit names 'one' to 'six'. In the control condition the experimenter merely spoke a nonsense syllable 'ba', at the same rate. As might be expected, the pattern of interference followed that of Expt. III, though subjects found it relatively easy to learn to ignore the interference. One interesting feature of this experimental technique is that the interference of the digits could be greatly increased by speaking the digit name always at the instant that the subject turned up a card. The subjects remarked that digits spoken at other times were easy to ignore. Future experiments will investigate this critical timing more exactly.

No 'shared modality' based hypothesis can encompass the above result, and so, on the principle of economy of explanation, that group of hypotheses must be eliminated as a possibility, when compared with the model in Fig. 3, for in the latter we can merely say that a symbol name can arise from auditory as well as visual stimulation, i.e. duplicating fewer features of the system than with the alternative hypothesis.

Experiment VI: Auditory interference with auditorily based task

Subjects were required to count the number of times the experimenter spoke a particular word. Words were repeated from one to six times at the rate of 3 per sec., the final word being signalled by a falling intonation. The subject responded vocally, stimuli and responses being recorded on a pen-recorder. There were two conditions, which paralleled the two experimental conditions in Expt. V, with the stimuli being common words or digit names. About 40 examples of each were given to each subject. Reaction times in the two conditions, words and digits, for three subjects were respectively S1: 0·46 sec. *v.* 0·67 sec. ($P < 0{\cdot}001$); S2: 0·32 sec. *v.* 0·37 sec. ($P < 0{\cdot}05$); S3: 0·45 sec. *v.* 0·54 sec. ($P < 0{\cdot}05$).

Modality generalization

The results of the previous two experiments require that we slightly elaborate the model in Fig. 3 to take account of the interaction between modalities. The crudest way of doing this is shown in Fig. 4, where there is a simple duplication of all the functions in Fig. 3 prior to the mediation. Such a formulation requires at least three

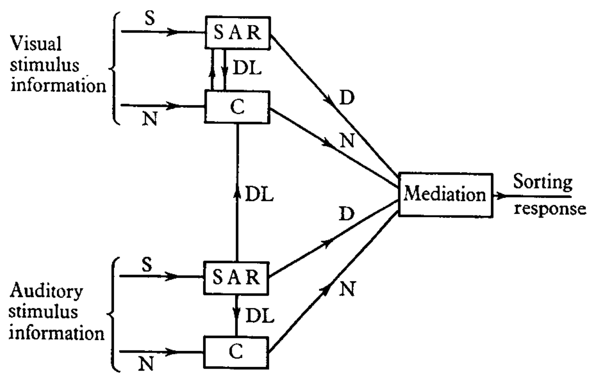

Fig. 4. A model which indicates cross-modal interaction.
(For key to symbols see Fig. 3.)

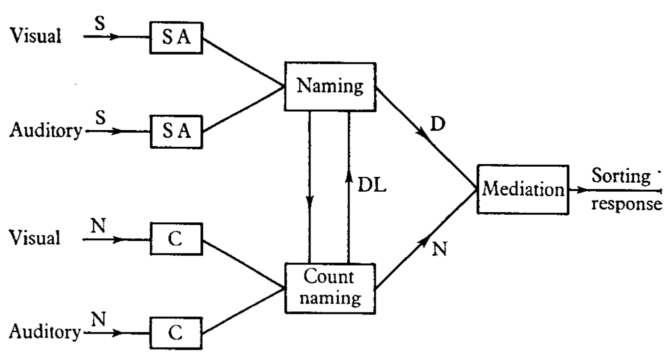

Fig 5. A more economical model than Fig. 4.

general interference pathways, *DL*, and some duplication of function which is unnecessary. We can instead combine the symbol-naming function, on the one hand, and the count naming functions on the other hand, which procedure, shown in Fig. 5, requires only a single interference channel. The resulting separation of symbol analysis and symbol naming is intuitively reasonable and will also be justified below. The model in Fig. 5, however, has two drawbacks. First, it postulates that there are two separate locations at which the digit names are available, and also, by analogy with the basic Stroop result, two locations where colour names are available. In addition, from Expt. IV, there would be two locations where the words 'left', 'right' and 'centre' were available. Such duplication is both uneconomic and unnecessary. The second drawback is that there is no ready explanation as to *how* the symbol names 'D' or 'full', for example, could interfere with the count-naming process which is concerned with digits.

BASIC MODEL PROPERTIES

Thus although the model in Fig. 5 is correct in some points of principle compared with alternative explanations, it is clearly insufficient in detail. The points of principle established are: (1) that there is verbal mediation, (2) that the interference is not entirely a question of sorting-response competition, and (3) that the interference is not stimulus-based but takes place after the convergence of the visual and auditory input channels.

The two objections raised to Fig. 5 can be removed by reconsidering the form of the model after the convergence point. The important feature of the following extension, as far as the methodology of theorizing is concerned, is that it was previously elaborated to account for the effects of context on word recognition, a totally separate class of phenomena. Thus the consequent diversity of application of the system more than compensates for its slight increase in complexity.

The first stage is to consider the notion of 'the availability of a response'. By 'available' is meant that the response could be made immediately without any further stimulus (or context) information being necessary. The response may of course actually be made, but this is irrelevant for what follows. Now, if you hear or see the word 'chair', if you see the object or a picture, if you are asked to complete the sentence 'he sat down on the...' of if you free associate to 'table', the same response is available, whether or not the response is made. Morton (1964*b*, *c*; 1969) has remarked that it is economic to assume that, in the process of a response becoming available, the same 'unit' is involved, regardless of the source of information. These units have been called 'logogens'. A *logogen*, then, is the place at which all information relevant to a particular *response* converges, regardless of the source of the information, and from which the response is made available. So the hypothesis can be made that, when a stimulus has a name and the stimulus affects behaviour by virtue of its name and not its 'pure' stimulus properties, it does so only when that logogen is involved which makes the name of that stimulus available. The point of this hypothesis is that that which distinguishes the stimuli 'two', '2' and '//' from the stimuli 'three', '3' and '///' (as far as their influence on behaviour is concerned) is their name.

When a word is available as a response it is suggested that it is coded in a 'response buffer' and it is assumed that only one response can be made available at any instant, i.e. responses have a temporal order in this memory. Digit names 'one' to 'six' in this store are then used to mediate the sorting response. This modified structure is shown in Fig. 6 and satisfies the two objections raised to Fig. 5. It has only a single location at which any name is made available. The problem of *how* the interference takes place is answered, since any nameable symbol will interfere with the sorting when its name is available before the count name. The former, entering the response buffer, will delay the latter, since the postulated channel will only accept the one name at a time.

ASSOCIATIVE INFLUENCES

In the model which forms the basis of the last modification, it is suggested that extensive connexions exist between those logogens which are concerned with responses which are in some sense related. (This crude associationalist statement is to be regarded as no more than a summary statement for a far more complex system;

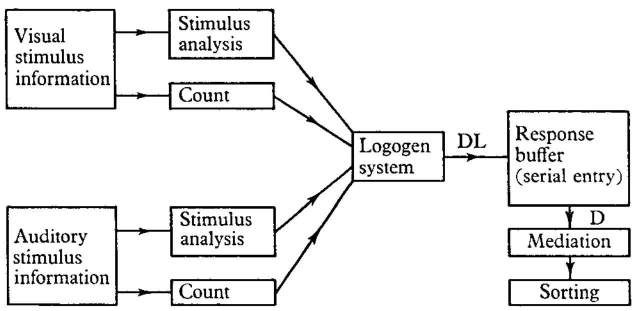

Fig. 6. The final model.

cf. Wales & Marshall (1966). It will, however, serve our present purposes.) These connexions operate whenever we are asked to free associate to a given word or when we are given a verbal context, but also function whenever information flows through the verbal system. Such information, arriving at a logogen, interacts with the analysed stimulus information to increase the likelihood of the appropriate response being available in much the same way that a context reduces the visual duration threshold for a word (Morton, 1964*b*). In addition, the likelihood of a response becoming available is increased by the response having previously been available. This latter effect is well known in the literature as 'priming' (Storms, 1958) and provides an additional, or alternative, explanation of the greater effect of digits to that of letters or words, since the digit names, according to the present theory, will become available in the course of sorting. Subsequently less stimulus information would be required to elicit the digit name and the likelihood of the digit symbol names delaying the count names would be increased.

Two further predictions can now be made. Firstly, we would expect less interference from the symbols '7', '8' and '9' than from '3' '4' and '5', since the logogens of the former set would not be directly primed in the course of sorting, nor would they mediate incorrect sorting responses. We would, however, expect '7', '8' and '9' to have more effect than the letters 'J', 'K' and 'L', since the logogens of the digit set would undergo secondary priming through associative links with the digits 'one' to 'six'.

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Experiment VII ($n = 12$)

The subjects sorted successively packs with shapes and two digit packs. On one of these packs the symbols were the digits 7, 8 or 9, and on the other the digits 3, 4 or 5. These packs will be referred to as D_7 and D_3 respectively. Each subject first had two practice sortings with the *S* pack and then two trials. The mean times are given in Table 5(*c*). The results for the D_7 pack are similar to those found with the letter pack in Expt. I. Thus the effects previously shown with the *D* pack are due to interference not by digits in general, but primarily by digits which are also used as sorting responses.

Experiment VIII ($n = 24$)

After practice with the *S* pack, 12 subjects sorted a pack (L_J) with the letters J, K and L and then the D_7 pack. There was no difference between L_J and D_7, presumably because the practice effect was too great. Accordingly another 12 subjects sorted the packs in the order S, D_7, L_J. The results for these two groups, ignoring the practice trials, are given in Table 5(*d*). When the groups were pooled, the difference between *L* and *D* was significant at $P < 0{\cdot}025$.

The last two experiments can be related to a study by Klein (1964), who repeated the original Stroop experiment, comparing the effects of different sets of words upon the time taken to name the colours in which the words were printed. He showed that words which were associated with the colours, such as 'sky' and 'lemon', produce larger effects than other words, but not as large as when the colour words themselves are used. These results can be seen as equivalent to Expts. VII and VIII above. In addition, he showed that high-frequency words interfered more than low-frequency words. Now it is well established that the visual duration threshold for high-frequency words is lower than for low-frequency words (Soloman & Howes, 1951). Broadbent (1967) and Morton (1968) have shown that this must be because less stimulus information is required to make high-frequency words available as responses. Accordingly, in the present frame of reference we would expect them to interfere more with the primary task of colour-naming.

THE EQUIVALENCE OF CHANNELS

It is essential to the form of the present model that the sources of information are equivalent, i.e. that interference is potentially mutual. Thus we would predict that numerosity *per se* would interfere with a sorting task based on the identification of digits. This was demonstrated in the following experiment.

Experiment IX ($n = 12$)

Subjects first sorted into the six piles a pack of 36 cards on each of which was a single digit, 1–6. This they did three times, the mean time on the last trial being 46·3 sec. They then sorted the *D* pack, but again by the digit, not by the number of digits as in previous experiments. The mean time was 48·2 sec., this being significantly larger ($P < 0{\cdot}005$) than with the single digit pack.

By analogy with the preceding experiments, it would appear that numerosity names are available as responses spontaneously. Intuitively we would expect this to be less likely than for the digit names, being less highly practised, and a comparison of the differences between the times in this experiment with the differences between the S and D packs on the first trial of Expt. I shows the latter difference to be greater (Mann–Whitney, $P < 0{\cdot}05$). It might be argued that the result of this experiment is merely due to the presence of an irrelevant dimension in a way similar to the result of Archer *et al.* (1955). In this and similar experiments, however, the irrelevant dimensions are truly orthogonal. In the present situation the presence of more than one symbol might facilitate the speed with which the digits were recognized. This supposition was confirmed by displaying single digits 1–6 in a tachistoscope with an exposure time which gave an average of 55 per cent correct. When a variable number of digits were presented, in the form of the D pack, the correct responses averaged 69 per cent for six subjects. Each subject had two blocks of 10 stimuli of each kind. All subjects showed the difference. The equivalence of the postulated channels is clearly related to a result by Rabbitt (1962), who showed subjects various letters in different colours and required them to recall letters and colours separately in an order specified either before or after the presentation. The differences between the two conditions were the same, regardless as to which of the features were recalled first, indicating that colour and letter information are separable at some level, and are in some sense equivalent.

Alternative models

The model proposed suggests that the primary interference effect occurs as verbal responses become available. Two further alternative explanations can be considered.

1. Recognizing a symbol could directly affect the counting process or inhibit its output to the naming mechanism rather than blocking the output from the latter as the present model suggests. This theory would still have to include some such system as the logogen system to account for Expt. VIII and Klein's results. Also, to be consistent, it would have to state the converse, that a counting output interferes with the digit recognition system (in order to account for Expt. IX), and that symbol recognition interferes with position sensing (Expt. IV). To include the basic Stroop result, the theory would also have to suppose that word recognition interfered directly with the process of colour recognition. *Ad hoc* suggestions of feedback effects of this generality lose their plausibility and are less cogent than the following alternative.

2. All cognitive processes may involve the same central mechanism which could be regarded as a general-purpose computer (cf. Broadbent's P system; Broadbent, 1958) so that the processes of symbol and colour recognition and counting are competing, as it were, for the same computing space.

However, one would expect that the more easily recognizable stimuli (i.e. those producing greater interference) would require *less* processing at such a level, thereby interfering less at that level, since less stimulus information would be required for their recognition. While such a feature may be operating, we would still require the subsequent system to explain the data.

LEARNING TO AVOID INTERFERENCE

It remains to account for the learning effect shown in Expts. I and II. This can be done by drawing an analogy between the two kinds of information in the present situation, numerosity and symbol type, and the two channels postulated for the dichotic listening situation (Broadbent, 1958). Treisman (1960), extending Broadbent's ideas, has suggested that we are able to shadow a message on one ear and more or less ignore a simultaneous message on the other ear by keeping the messages separated into two channels and attenuating the signal on the rejected channel. Treisman points out that it is necessary to specify 'attenuation' rather than 'blocking' since words on the rejected channel which are probable were in fact sometimes given as responses. Treisman's model also contains a dictionary with units corresponding to words; and the correspondence between the two experimental situations is made more complete by supposing that what is learned in the card-sorting task is the attenuation of symbol stimulus information. This would take place prior to the logogen system if the analogy holds. The attenuation had the *effect* of reducing the signal-to-noise ratio of a channel, in which situation the probability of recognizing a stimulus on that channel, i.e. of the incorrect response being available, is reduced. (This is in effect a definition of the usage of 'attenuation'. It is not meant to imply that the 'attenuator' functions by selectively reducing the signal amplitude—there are at least three different mechanisms which could produce the same effect—or that the 'channels' in the two situations are physically identical. In addition, the current controversy as to the location of the blocking (Deutsch *et al.*, 1967) does not affect the present discussion.) In Expt. I, then, the probability of a symbol name being available was reduced, and hence the difference between the *S* and *L* packs was no longer detectable. The *D* pack retained its influence because of 'priming' effects, although its effect was reduced as much as that of the *L* pack. Thus, since the responses 'one', 'two', etc., are made available in mediating the sorting, little sensory information will be required concerning the symbols '1', '2', etc. (i.e. with the *D* pack) to make the same responses available again as interfering digit names. Much more symbol information would be required, however, to make the letter names available with the *L* pack, and so its interference effects will still be less. In Expt. II, where the cards had to be studied more carefully, more symbol information would be available for both the *D* and the *L* packs than in Expt. I. Accordingly, we would expect more interference in Expt. II where the situation may be regarded as analogous to increasing the duration of a tachistoscopic exposure. The lack of differential improvement between the *D* and *L* packs in Expts. I and II indicates that the learning effects take place before the output from the logogen system. Thus any alternative explanation based on class selection by response bias, i.e. discriminating against letters, is not supported by the data. Indeed, if anything, in Expt. II performance on the digits improves more than with letters. It is possible that the progressive reduction in the effects of *L* and *D* in Expt. I was brought about by the subjects learning the patterns which corresponded to the responses and so possibly avoiding verbal mediation altogether for some of the responses. Such a suggestion is partially countered by the observation that some subjects increased the amount of overt verbalization on the third trial.

Rabbitt (1967), however, presents data which cannot be explained in this way. In brief, his experiments require the subject to identify one of two or one of eight particular letters embedded in varying numbers of other irrelevant letters. When the set of irrelevant letters was changed there was a decrement in performance, provided the subjects were practised. Such sources of information, of course, cannot be regarded as separate channels in the present sense, since the distinction between 'relevant' and 'irrelevant' letters can only be made after the letter has been recognized. Rabbitt explains his results by proposing that the subject develops a special cue system in the course of training which enables him to make minimal distinctions between relevant letters and the set of irrelevant letters. In the present system this would take place at the level of stimulus analysis.

Other interference effects

Experiment X ($n = 12$)

The effect of higher order processing upon sorting was demonstrated by comparing performance on the word pack used in Expt. III with that on two packs so arranged that successive words made up a simple story. The task, as before, was to sort the cards by the number of words on the cards, and it was thought that the presence of a story line would increase the sorting time. A preliminary experiment showed this not to be true for the reason that the subjects never noticed the story. Typically the subjects reported that they had just noticed a few words but thought the packs the same kind as before. This is rather similar to Epstein's (1962) findings that a grammatical string presented word by word in a memory drum is no easier to remember than a randomized string of words, as subjects do not notice the syntactic constraints which might otherwise facilitate learning.

Accordingly, when subjects had not noticed the nature of the first prose pack they were informed of it, told that the next pack would have a story on it, but that they were to take no notice of it, merely sort as before. In spite of these instructions, all subjects in this subgroup took much longer over the second prose pack, many of them complaining that my telling them of the existence of a story had made it impossible to ignore. The mean times for sorting were: words, 51·8 sec.; story 1, 49·5; story 2, 53·1. Only one out of 12 subjects could ignore story 2. All the five subjects who noticed story 1 took longer over it than the word pack, and improved on story 2.

Experiment XI ($n = 6$)

All the previous experiments involved interference between sources of information which were easy to conceptualize as different channels. This experiment looks at a situation in which it is not so; accordingly, we would expect the interference effect to be greater than before. The primary task was to sort a pack of cards (Y) into six piles by the number of crosses on the card. There were 1–6 crosses arranged in a single vertical column. The interference pack (Yx) had a rectangular matrix of crosses, the task being to sort by the number of crosses in the column, i.e. by the number of rows (see Fig. 1 *g*, *h*). The interfering information was the other dimension, i.e. the number of columns.

Subjects practised twice with the Y pack and then had three trials of a Y pack and a Yx pack. The mean times were:

$$Y_1 = 50,\ Yx_1 = 60{\cdot}5;\ Y_2 = 50,\ Yx_2 = 53{\cdot}5;\ Y_3 = 46,\ Yx_3 = 51.$$

All subjects showed the inequalities in all three trials. The differences between packs in the first trial were significantly larger than those on the first trial in Expt. I (Mann–Whitney, $P < 0{\cdot}001$).

This comparison is analogous to Treisman's findings (1964*a*, *b*) that the ease of rejecting a competing message is greater if the voice is the same as with the accepted message, if the material is similar, if the phonemic system used is similar. Such results are clearly accountable for within the same system as the data presented above.

Conclusion

The experiments are summarized in Table 6. It has been shown that in a sorting task which appears to be mediated by a verbal response, those irrelevant features of the cards sorted which have names will interfere with the task. The extent of the interference appears to be a function of: (1) the relation between the irrelevant feature and the mediating response irrespective of modality (Expts. I–VIII; Klein) (2) the relation between the structure of the irrelevant feature and the relevant feature (Expt. XI *v.* I; Treisman); (3) the amount of information regarding the irrelevant feature which is available or impinges (Expt. II *v.* I); (4) the amount of information given to the subject regarding the irrelevant information (Expt. X).

Alternatives to the present model would seem either to fall under the criticisms already made or to question one of the two crucial assumptions, i.e. that the sorting is verbally mediated, or that the same response always comes from the same logogen, regardless of the source of the information. The first of these assumptions rests on observation and introspection and the second on the body of data accounted for elsewhere (Morton, 1964*b*; 1969).

Table 6. *Summary of experiments*

I	Regular patterns; Arabic digits > letters > control; general learning effect over three trials.
II	As I but without regular patterns. All times greater than I. Less learning than in I.
III	Digit names > words > control.
IV	Position sorting. Position names > words > control.
V	Auditory interference with sorting. Digits > words.
VII	3, 4, 5. > 7, 8, 9.
VIII	7, 8, 9. > J, K, L.
IX	Numerosity affecting sorting by digit but facilitating digit recognition.
X	Effect of story.
XI	Effect of number of columns on counting rows of a matrix.

One feature running through all the experiments is the autonomous nature of the recognition process. Such a feature presents great difficulties for any active or motor theory of speech perception (Liberman *et al.*, 1962, 1967; Morton & Broadbent, 1967). To a lesser degree, from the result of Expt. VII we would also want to claim that the counting process was autonomous, related to what has previously been called 'subitizing' (Kaufman *et al.*, 1949).

It might be possible to account for the results presented above separately by attributing different causes to the various results. In this case the criterion of parsimony of theoretical constructs would have to be applied. It is not claimed that all effects previously accounted for by theories, such as the various alternatives which have been rejected above, can be explained in terms of the above model; it is sufficient to demonstrate that the processes described are minimal and necessary for the present data and the results originally encompassed by the component parts. In addition, the framework which has been evolved contains features which can be utilized in accounting for other data; all that is required is to specify the *properties* of these features in a manner similar to the discussion of Rabbitt's results above. The framework has also been used as a basis for discussion of a number of phenomena in short-term memory (Crowder & Morton, 1969).

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