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INTERACTION OF INFORMATION IN WORD RECOGNITION[1]

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Quantitative predictions are made from a model for word recognition. The model has as its central feature a set of "logogens": devices which accept information relevant to a particular word response irrespective of the source of this information. When more than a threshold amount of information has accumulated in any logogen, that particular response becomes available for responding. The model is tested against data available on the effect of word frequency on recognition, the effect of limiting the number of response alternatives, the interaction of stimulus and context, and the interaction of successive presentations of stimuli. The implications of the underlying model are largely upheld. Other possible models for word recognition are discussed as are the implications of the Logogen Model for theories of memory.

In previous papers a functional model for word recognition has been developed (Morton, 1964a, 1964b, 1964d; Morton & Broadbent, 1967). The form of description used only lent itself to qualitative predictions and while it seemed to have some heuristic value, the overall system was too complex to allow rigorous specification of its properties. In the present paper the model is first outlined in a slightly simplified way and then certain features of it are isolated in order to make quantitative predictions about performance in word recognition. The various predictions made are largely independent and have in common only the fact that in all situations there is some stimulus information present. The effects of word frequency are taken to indicate relatively permanent changes in the system; the effects of having a reduced set of alternative responses involve temporary changes in the same variable. Different predictions are made concerning the interaction of a context with the stimulus and the effects of repeated presentation, these differences arising from differences in the potential sources of such information. The model contrasts most completely with explanations of word recognition which would ascribe all the observed effects as being due to "guessing" habits.

While in conception the model is very complex and highly interacting, it should be noted that the separate sections can be judged in isolation. In the description of the model a number of variables are introduced to account for primary observations. The implications of most of them are tested in the sections that follow.

Description of the Model

The basic unit in the model is termed a *logogen*.[2] The logogen is a device which accepts information from the sensory analysis mechanisms concerning the properties of linguistic stimuli and from context-producing mechanisms. When the logogen has accumulated more than a certain amount of information, a response (in the present case the response of a single word) is made available. Each logogen is in effect defined by the information which it can accept and by the response it makes available. Relevant information can be described as the members of the sets of attributes $[S_i]$, $[V_i]$, and $[A_i]$, these being semantic, visual, and acoustic sets, respectively. More detailed suggestions as to the properties of these sets are given elsewhere (Morton, 1968b). Incoming information

[1] Part of this paper was written while the author was at the Department of Psychology, Yale University, supported by Grant MH 14229 from the National Institutes of Mental Health to Yale University. The author is grateful to W. R. Garner for the use of much of his time.

[2] From *logos*—"word" and *genus*—"birth." The author is indebted to Hallowell Davis for suggesting the term.

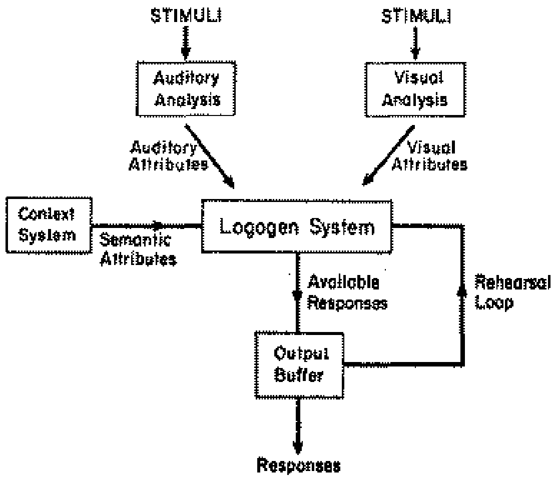

FIG. 1. Flow diagram for the Logogen Model.

has only a numerical effect upon any logogen which merely counts the number of members of its defining sets which occur, without regard to their origin. When the count rises above a *threshold* value, the corresponding response is made available.[3] Available responses go to the Output Buffer, whence they may emerge as actual responses or be recirculated to the Logogen System in a "rehearsal loop." This idealized model is diagrammed in Figure 1.

Since this system operates during reading and listening to continuous speech, it is necessary to assume that the value of the count decays very rapidly with time, returning to its original value in something of the order of 1 second. Otherwise words with a structural similarity to the ones spoken would become available uncontrollably. When a context is presented in an experiment, however, the Context System can operate almost continuously to maintain constant the levels of the counts in logogens affected by that context. Stimulus effects must remain transitory unless a portion of the stimulus has been recorded in some verbalizable form such as "A three-syllable word" or "A word with an initial *p*." Such verbalizations would act in a way similar to that of a context and produce lasting effects, which might hinder the subject if the information were incorrect.

In the complete model the nature of the relationship between the Logogen System and the Context System is such that there is continuous exchange of information between the two, which does not result in responses becoming available and which is uncorrelated with the objective features of the experiment (see Morton, 1968b). This activity affects the values of the counts in the various logogens and it is assumed that samples of the values of the counts would be distributed in a way which approximates the normal distribution and that all logogens would have identical distributions. It is further assumed that such activity is the only source of apparent noise in the system. Logogens can thus be regarded as behaving in a manner similar to detectors described by signal detection theory (Green & Swets, 1966). Figure 2 illustrates the state of a logogen under various conditions. Diagram 2a represents its normal state, the ordinate being a probability distribution. The range of the count is such that its value very rarely exceeds the level of the threshold and, on average, t items of relevant information are required at any one time before the corresponding response will be available. The effect of a context is to raise the mean of the count by an amount c, as in Diagram 2b. In this case only an average of $(t-c)$ further units of information will be required to produce a response. The effect of a stimulus is similar, as shown in Diagram 2c, but, as previously mentioned, the stimulus, unlike the context, is not self-sustaining. When both context and stimulus are present, the units of information add, and an average of only $[t-(s+c)]$ units are required to produce a response, as shown in Diagram 2d.

Logogens have one further property, in that following the availability of a response, the threshold of the logogen is lowered to a

[3] It should be noted that this use of the term "available response" differs slightly from the concept of "availability" as used by other writers on memory (e.g., Tulving & Pearlstone, 1966) and word recognition (e.g., Eriksen & Browne, 1956). Previous usage refers to a continuum of availability which corresponds more nearly to the current level of the threshold of a logogen in the present model. An "available response" is related to the old term "implicit response" (Miller & Dollard, 1941) but is more limited in its application in some rather fundamental ways.

certain level γ, returning to a value slightly less than the original value with a time constant which is very long in comparison with the time constant of the count decay. This property was originally required to explain the fact that in a word-recognition experiment subjects often give as erroneous responses words which have occurred as responses earlier in the experiment (Morton 1964c). It is assumed that such a property is also reflected in the fact that words of high frequency of occurrence are, in general, more intelligible in noise than low-frequency words. In terms of the Logogen Model we would say that logogens corresponding to words of high frequency in the language have lower thresholds. Since the requirement for such threshold lowering is the response becoming available, and not necessarily the response being made, both frequency of emission and frequency of reception will affect the threshold.[4] The short- and long-term effects of word repetition are shown in Diagram 2e. The short-term effect is called the γ factor (and will be a function of time); the long-term effects are shown by the threshold lines marked H. F., M. F., and L. F., corresponding to high-, medium-, and low-frequency words. It can be seen that the effect of a lower threshold is equivalent to the effect of having contextual information in that both reduce the amount of sensory information which would be required to take the level of the count above threshold.

It is assumed that the system is *passive*, in the sense used by Morton and Broadbent (1967), as opposed to *active*. As the system operates, no comparisons are made by any mechanism external to the Logogen System of the levels of activation in different logogens. Decisions are only made within each logogen. Thus more than one response could be available following the presentation of a single stimulus. The further assumption is made, however, that the exit from the Logogen System to an Output Buffer is a single channel, and thus the first such response to become available will have precedence.

[4] See Morton (1964d) for a discussion of the emission versus reception controversy.

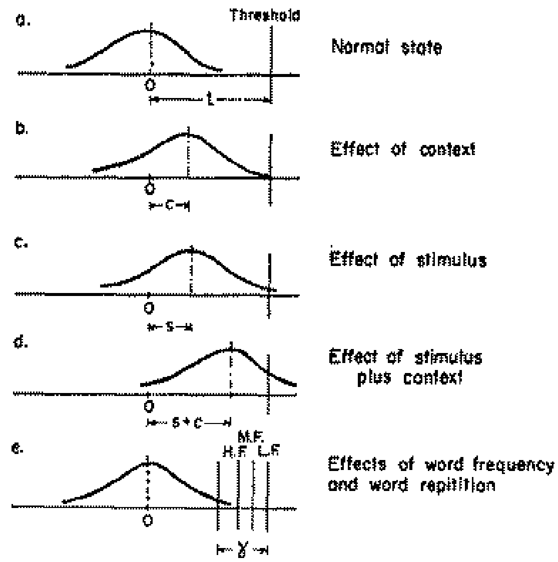

FIG. 2. The effects of certain situations upon the state of a logogen. (The horizontal axes represent the level of excitation—or similar analogy—in the logogen. The curves correspond to probability distributions of the excitation. The vertical lines represent the threshold of the logogen. When the level of excitation exceeds the threshold the corresponding word is available as a response.)

MATHEMATICAL TREATMENT

The full treatment of a system such as the one described above by signal detection theory has not yet been worked out. Instead predictions will be made from the response strength model (Luce, 1959). For present purposes Luce's model may be regarded as a logarithmic transformation of a Thurstonian or a signal detection model. Thus where effects add in the latter system, as in Figure 1, they are multiplied in the response strength model. The first step is to assign response strengths to all possible responses in a given situation. This is equivalent in the Logogen Model to assigning a value to the difference between the current level of activation and the threshold for every logogen. The probability of any particular response becoming available is then given by the ratio of the response strength for that item divided by the total of the response strengths for all the possible responses. This is termed the *Ratio Rule.* Since ratios and not absolute differences are critical in this form of analysis we are free to scale the assigned values. Thus when we are considering the effects of a stimulus we will say that the response strength of the correct logogen is α compared with a value of unity for all other logogens. This is not to say that the stimulus has no effect on the other logogens, merely that on average the effects will be the same for all the others. The value of α then is properly regarded as the difference between the effects on the stimulus logogen and the average of all others. The state of the logogens when the stimulus is presented is contrasted symbolically with the effect of the stimulus by use of the letter V. This letter will be used to designate the differences in threshold between logogens and also the differential effects of context. The combined effects of the stimulus together with one of the other factors is calculated by multiplying the response strengths of the two effects for each logogen. This is equivalent to adding the effects in Figure 1d. In the case where we have assigned a value of 1, as in Table 2, the multiplication in the response strength analysis is equivalent to saying that there is no effect of the stimulus on that logogen. Throughout this paper it should be remembered that the mathematics is only used to predict the operation of the system which is described above.

Predictions from the Model

Word-Frequency Threshold Effect

A number of authors have shown that intelligibility in noise and the visual duration threshold for words are strongly influenced by the frequency of occurrence of the words, and there has been much controversy as to whether such results should be attributed to "stimulus effects" or "response effects" (Broadbent, 1967). Within the Logogen Model, which in this respect resembles Broadbent's own treatment, the dichotomy is scarcely applicable (Morton, 1968a).

By the model the difference between words of differing frequency of occurrence is that the logogens have different thresholds. Thus the logogens corresponding to high-frequency words will require less stimulus information for the count to rise above the threshold. The amount of stimulus information available to a logogen is, however, assumed to be independent of the frequency of the word and is a function only of the properties of the stimulus (duration, contrast, signal-to-noise ratio). Thus we will say that the presentation of a stimulus increases the response strength of the stimulus logogen to an amount α compared with all other logogens, whose strength remains at unity. (Since we are concerned with ratios, the latter value is arbitrary and simply serves to scale α.) This is not to say that it is assumed that all other words are equally confusable with any stimulus word, merely that stimulus confusions are unrelated to word frequency. This is the "principle of acoustical equivalence" suggested by Brown and Rubenstein (1961). These authors investigated the word-frequency threshold effect, dividing the 6500 monosyllabic content words into 13 classes of 500 words each, the classes being formed by grouping the words by their frequency. They presented subjects (*S*s) with a total of 1300 words, consisting of a randomized selection of 100 words from each frequency interval in noise, and calculated c_i, the number of responses which were correct in each interval, i, and s_i, the number of responses which were in the same frequency interval as the stimulus (but might have been incorrect responses).[5]

The latter measure includes c_i, however, and so cannot be compared with it; instead we will use e_i, the number of incorrect responses in the same frequency interval as the stimulus.

Morton (1968a) has tested a series of models against Brown and Rubenstein's data, rejecting single-threshold models which claim that the word-frequency effect is entirely due to response bias and a model by which the effect is entirely due to the stimulus, in which α would be a function of word frequency. For the model at present under discussion, the response strengths appropriate to the different responses in this situation are given in Table 1. If the

[5] The author is grateful to H. Rubenstein for kindly providing his original data.

TABLE 1

RESPONSE STRENGTHS IN THE WORD-FREQUENCY EXPERIMENT

Stimulus class	Correct responses	Incorrect responses of interval			Total of strengths
		1	i	n	
1	$\alpha_1 V_1$	$(M-1)V_1$	MV_i	MV_n	T_1
i	$\alpha_i V_i$	MV_1	$(M-1)V_i$	MV_n	T_i
n	$\alpha_n V_n$	MV_1	MV_i	$(M-1)V_n$	T_n

assumption concerning the invariance of the amount of stimulus information with word frequency is correct, all α will be equal.

The differences in thresholds of logogens in different frequency classes are indicated by the variables $V_1 \cdots V_i \cdots V_n$. M is the number of responses in each frequency class. The probability of a correct response in the interval i is thus given by the equation

$$c_i = \frac{\alpha_i V_i}{T_i}. \qquad [1]$$

The probability of an error response being in the correct frequency interval is given by

$$e_i = \frac{(M-1)V_i}{T_i}. \qquad [2]$$

Combining Equations 1 and 2 we obtain

$$c_i = \frac{\alpha_i}{M-1} \cdot e_i. \qquad [3]$$

Since in the present model α_i is independent of i, we predict a linear relationship between c_i and e_i. The data are plotted in Figure 3 with the best fitting straight line. The nonzero intercept and the possible slight curvature in the data are capable of several explanations, any of which would require slight modifications to the model. However, all the alternative models tested can be rejected out of hand (Morton, 1968a).

The Interaction of Set Size with Signal Level

A number of experiments have been performed in which *S*s have been presented with a stimulus word which has been selected from a restricted set of known alternatives. The general result is that the intelligibility of a stimulus is increased as the number of response alternatives is reduced. With the present model the known alternatives would have their thresholds lowered to a level γ. This would serve to make the response strengths of other responses small by comparison; to a first approximation they can then be ignored in the analysis. We can then regard the response strength of the stimulus word as being α compared with unity for all the other alternatives. This again assumes equal confusability between the alternatives—an assumption which is certainly not true and would result in a relative lowering of performance. In addition it assumes that the average confusability of the alternatives is independent of their number. Since, as before, α represents the difference between the stimulus information received by the stimulus logogen and the average of that received by other logogens, violation of this assumption would lead to different

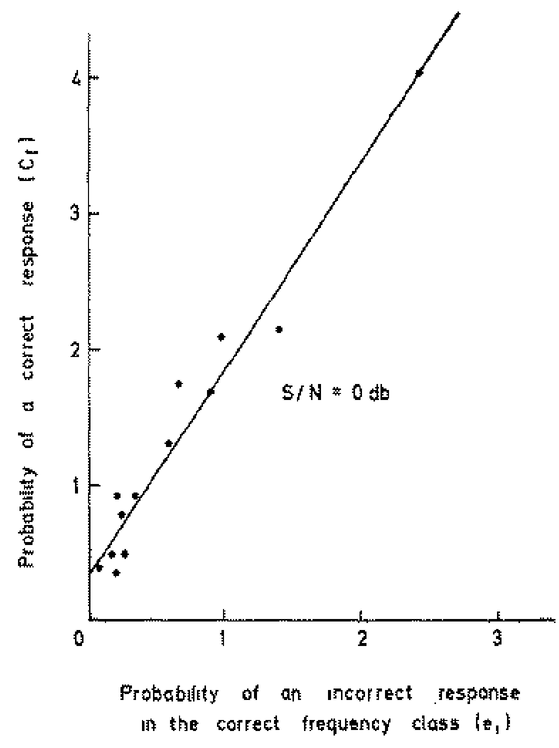

FIG. 3. Data from Brown and Rubenstein (1961). (The abscissa, e_i, is the probability of an incorrect response to a stimulus in the ith frequency interval itself being in the ith interval. C_i is the probability of a response to a stimulus in the ith interval being correct. The line is the least squares fit.—From Morton, 1968a.)

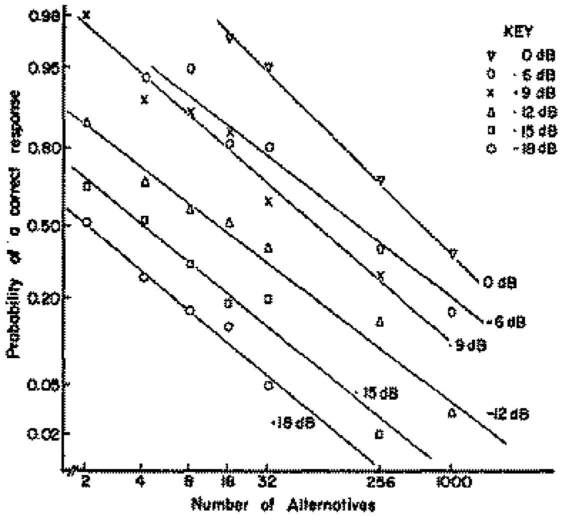

FIG. 4. Data from Miller, Heise, and Lichten (1951), showing variation in performance with different numbers of alternatives. (The function plotted is: logit $P_n = \log \alpha - \log (N-1)$. The lines are the least squares fit. Logit $P_n = \log [P_n/\{1 - P_n\}]$.)

predictions. While it is unlikely to be true, it will, however, serve as a first approximation.

With these assumptions the probability of producing a correct response at any S/N with N alternatives is given by:

$$P_n = \frac{\alpha}{\alpha + (N-1)}. \qquad [4]$$

This can be rewritten as

$$\frac{P_n}{1-P_n} = \frac{\alpha}{N-1} \qquad [5]$$

whence

$$\text{logit} P_n = \log \alpha - \log (N-1) \qquad [6]$$

where logit $P_n = \log[P_n/(1-P_n)]$.

Miller, Heise, and Lichten (1951) provide data against which this equation can be tested. In their experiment *S*s were presented with spoken monosyllables in different levels of masking noise. The words were chosen from known vocabularies of sizes ranging from 2 to 1000. The functions resulting from entering their data into Equation 6 are plotted in Figure 4. Only those S/N are used for which four or more points are available. It can be seen that the deviations from linearity are well within the experimental error in the data. The average slope of the resulting lines, fitted by the method of least squares, is $-.82$ which is reasonably close to the predicted slope of minus one.

There are several well-motivated modifications of the model which would lead to different predictions, but attempts to apply these would only add a small amount to the predictive and heuristic value of the model. The following are examples of the kinds of modification which might be made:

1. Breakdown of the assumption of equal average confusability of the alternatives could lead to relative changes in performance at any value of N in either direction.

2. With a small number of alternatives it is possible that *S*s would try to predict in advance the next item in the sequence. As the stimuli were randomized, this attempted prediction could only lead to an overall worsening in performance.

3. With larger numbers of alternatives it is possible that *S*s were in fact using a smaller number than that prescribed. The likelihood of their recognizing stimuli outside the subjective set would be much lower, but for values of α which were small compared with N it is possible that performance would improve. On the other hand, if the subjective set were larger than the objective set—if, for example, in the 1000-word condition the subjective set were the complete set of English monosyllables—performance on that condition would be apparently worse.

4. The present model assumes that the distribution of "noise" in the logogens is logistic.[6] Different assumptions about the distribution, equally well motivated, could make the model fit better or worse.

5. If the response strengths of the items outside the objective set are not negligible, we would obtain the equation

$$\text{logit} P_n = \log \alpha - \log[(N-1) + k] \qquad [7]$$

where k is the sum of the response strengths of the other items. Introduction of this

[6] The logistic distribution, required by the Response Strength mathematics, is similar to the normal distribution, differing chiefly in the tails.

constant could make the model fit the data almost perfectly.

None of these modifications would affect the underlying principles of the model. The best we can say then is that the model fits the data reasonably well. This is as much as any model can hope to do. It is, however, clear that by the above analysis the effect of increasing the signal strength is the same regardless of the number of alternatives.

Alternative Models

1. Green and Birdsall (1958) have plotted Miller et al.'s data by calculating values of d' for the different values of N, showing that d' is approximately independent of N. This procedure closely approximates the one used above and has essentially the same underlying model.

2. Garner (1962) has plotted the same data in terms of the number of bits of information transmitted, showing that this measure is essentially independent of N. This form of analysis makes no claims about the form of the underlying model and is perhaps better regarded as indicating, in general, that *S*s' efficiency remains independent of N. As such it is not an alternative model to the Logogen Model, but rather an alternative method of treating the data.

3. Stowe, Harris, and Hampton (1963) propose a model whereby words are discriminated by identifying them on a number of binary stimulus dimensions. The correct response is only given following correct identification on all the dimensions. $\log_2 n$ dimensions would be required to discriminate among n words. Thus in the two-choice situation only a single dimension would be used. If the probability of a correct decision on one dimension were P_d, and if all dimensions were equally well discriminated, then the probability of a correct identification among n alternatives would be given by $P_n = (P_d)^{\log_2 n}$. This model gives a reasonable fit to Miller et al.'s data. It appears to suffer a conceptual drawback, however, in that as the number of alternatives is reduced, the number of discriminating dimensions which the system uses is reduced. Some of the dimensions excluded from the discrimination process (presumably in some arbitrary way) could in fact provide usable information. The model is insufficiently explicit to enable further discussion.

It has been suggested that the effect of restricting the number of alternatives is to reduce the thresholds of the appropriate logogens to a common value γ. If this were so, then we would expect, as Pollack, Rubenstein, and Decker (1959) have shown, that word frequency does not exert a measurable influence upon the intelligibility of words in known message sets.

The Interaction of Stimulus and Context

There is a large body of evidence which indicates that the recognition of a word is greatly facilitated by the prior presentation of a context. The extent of the facilitation is a function of the likelihood of the context eliciting the word in a free-response situation. In most cases the context consists of an incomplete sentence which the stimulus word completes, but the analysis below can be generalized to any context. Three sources of data are required: the probability of the target word being given as a response to the context alone, in the absence of a stimulus; the probability of the response to a stimulus at a particular S/N in the absence of a context; and the probability of the response at that S/N when the context has already been presented.

Table 2 gives the appropriate response

TABLE 2

RESPONSE STRENGTHS WITH STIMULUS, WITH CONTEXT, AND WITH BOTH

Experimental condition	Correct response	Other responses to individual words	Total of response strengths
Stimulus only	α	$1 \quad 1 \cdots 1$	$\alpha + (N-1)$
Context only	V_i	$V_1 \; V_2 \cdots V_n$	$T = \sum_{i=1}^{n} V_i$
Stimulus and context	αV_i	$V_1 \; V_2 \cdots V_n$	$T + (\alpha - 1) V_i$

Note.—The entries in the third line are obtained by multiplying the entries in the first two lines. This is equivalent to adding the effects of stimulus and context in Figure 2d.

strengths for stimulus alone, context alone, and for the combination of stimulus and context. The response strengths for the combined condition are obtained by multiplying the strengths in the other two conditions. This table is intended, as before, to represent the average of all possible outcomes.

The probability of a correct response from the stimulus, P_s, alone is given by the equation

$$P_s=\frac{\alpha}{\alpha+(N-1)} \qquad [8]$$

from which we obtain

$$\alpha=\frac{P_s}{1-P_s}\cdot(N-1). \qquad [9]$$

The probability of a correct response from context alone, P_c, is given by

$$P_c=\frac{V_i}{T} \qquad [10]$$

from which

$$T=V_i/P_c. \qquad [11]$$

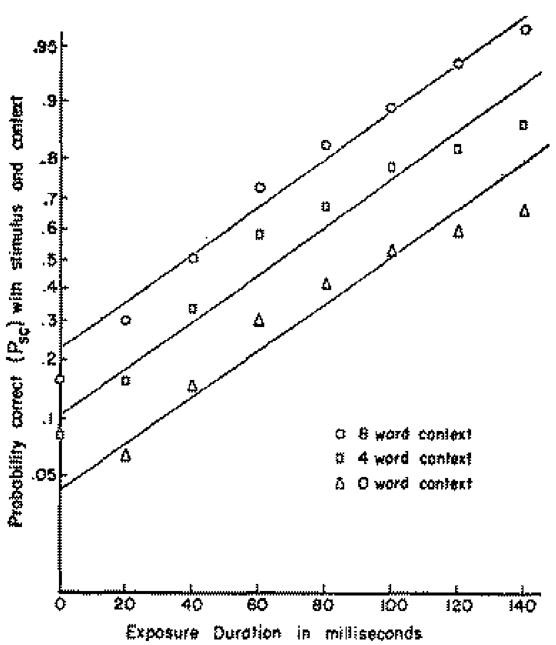

FIG. 5. Data from Tulving, Mandler, and Baumal (1964) on the joint effects of stimulus and context. (The function plotted is: logit $P_{sc} = a_i + bx$, where x is the exposure duration, P_{sc} is the probability of a correct response, and a and b are constants.)

With both context and stimulus, the probability of a correct response, P_{sc}, is

$$P_{sc}=\frac{\alpha V_i}{T+(\alpha-1)V_i}. \qquad [12]$$

If we substitute for α and T from Equations 9 and 11 in this equation, V_i vanishes and we are left, after rearrangement, with:

$$\frac{P_{sc}}{1-P_{sc}}=\frac{P_s}{1-P_s}\cdot\frac{P_c}{1-P_c}\cdot(N-1). \qquad [13]$$

If we take logarithms this equation can be written as:

$$\text{logit}P_{sc}=\text{logit}P_s+\text{logit}P_c+\log(N-1). \qquad [14]$$

It should be noted that the term $\log(N-1)$ is not a variable which can be considered as varying in the presence of a context, with or without a stimulus, since it is derived entirely from the condition where only a stimulus is given. It is thus unaffected by any effect the context may have in reducing the number of alternative responses. In fact, Equation 14 can be written as:

$$\text{logit}P_{sc}=\log\alpha+\text{logit}P_c. \qquad [15]$$

Tulving, Mandler, and Baumal (1964) provide data against which this equation may be tested. They presented *S*s with 18 words at successive durations ranging from zero, in fact a "word-like smudge," to 140 milliseconds. The *S*s had additional information in the form of zero, two, four, or eight words of a context sentence. They propose an empirically derived equation for their data:

$$\text{logit}P_{sc}=a_i+bx \qquad [16]$$

where a_i is a constant depending upon the level of the context, b is a constant, and x is the duration of exposure of the stimulus word. They do not present their data in the form of this equation, so it is given in Figure 5 with lines drawn from the constants they give. The data for two-words context are not given as they are almost identical to the values for four-words context. The data are a moderately good fit, but there is a curvilinear component apparent in all three of the context conditions.

In Figure 6 these data are replotted according to Equation 14 with the context level as the parameter. This has the effect of scaling the abscissa (the duration) according to the performance in the zero context condition. Lines of the predicted slope, unity, have been fitted by eye, and it will be seen that they approximate the data excellently except for the two highest exposure durations for eight-words context. From this we may conclude that, within the model we are using, the amount of stimulus information available to the Logogen System does not change when a context is present and does not vary with the amount of context information. In one sense stimulus information is independent of context information. Such a statement is only meaningful within the framework of a particular model and should *not* be interpreted in terms of the statistical independence model

$$P_{sc} = P_s + P_c - P_s P_c \qquad [17]$$

which is logically inappropriate in this situation since it would imply that the sources of information were equivalent. Clearly S would not choose his preferred "correct" response to the context in the face of apparently contradictory information from the stimulus as would be implied by Equation 17.

Equation 14 also predicts that logit P_{sc} will be linear with logit P_c with a slope of one. In the case of Tulving et al.'s data we would have only three points per line. In addition the estimate for P_c is extremely unreliable, consisting of only three correct responses out of a possible 450. The differences between P_{sc} with four and eight words of context are of the right order of magnitude at all except the two highest durations, the mean increase in logit P_{sc} being .332 for an increase in logit P_c of .325.

There do not appear to be any further data available against which to test Equation 14. Many authors have investigated the effect of context upon recognition, but

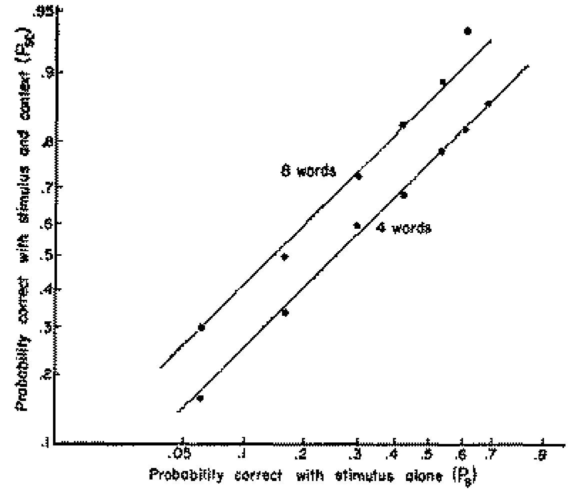

FIG. 6. The same data as in Figure 5; plotted as logit $P_{sc} = K +$ logit P_s. (The lines are fitted by eye with the predicted slope of unity.)

the form of the experiments renders them unsuitable, mainly because the method of ascending limits or some similar procedure has been used for each individual stimulus. In the earlier discussion it was pointed out that the effect of a response becoming available was to lower the threshold of the logogen to a level γ. Such an effect would occur whether the response were called for by the experimental procedure or resulted from S actively attempting to complete the sentence (or fulfill the requirements of another context) prior to the presentation of the stimulus. If the prior response coincided with the stimulus we would expect an increase in the proportion of the correct responses; if the prior response did not coincide with the stimulus we would expect poorer performance. The state of the response-strength table following various outcomes is given in Table 3. Where the correct response has been given prior to the presentation of the stimulus (what we may call the γ-plus case) the subsequent performance is predicted by the equation

$$\text{logit}P_{sc} = \log\alpha + \text{logit}P_c + \log\gamma. \qquad [18]$$

The γ-minus case, where a response has been given which is different from the stimulus, is not amenable to solution without knowing the complete distribution of responses to the context. The full solution

TABLE 3

RESPONSE STRENGTHS WHEN AN ANTICIPATORY RESPONSE HAS BEEN GIVEN

Situation	Correct response	Incorrect responses	Total
No prior response	αV_i	$V_1 V_2 \cdots V_j \cdots V_n$	$T + (\alpha - 1)V_i$
Correct prior response (γ-plus)	$\alpha\gamma V_i$	$V_1 V_2 \cdots V_j \cdots V_n$	$T + (\alpha\gamma - 1)V_i$
Incorrect prior response (γ-minus)	αV_i	$V_1 V_2 \cdots \gamma V_j \cdots V_n$	$T + (\alpha - 1)V_i + (\gamma - 1)V_j$

Note.—$T = \sum_{i=1}^{n} V_i$ throughout. The effects on the response strength of a prior response are obtained by multiplying the appropriate entry by γ. This is equivalent to a reduction in threshold of an amount γ in Figure 2e.

has the form

$$\bar{P}_{sc} = \sum_{j=1}^{n} \frac{\alpha P_c P_j}{\alpha P_c + (1 - P_c) + (\gamma - 1)P_j}, \quad (j \neq i) \quad [19]$$

where the values of P_j represent the probabilities of words other than the target word (Word i) being elicited by the context, and $\bar{P}_{sc}$ is the average outcome for any one target word. An approximation based on the assumption that all other responses have equal response strengths gives the equation, to be compared with Equation 15,

$$\text{logit} P_{sc} = \log\alpha + \log\frac{P_c}{(1 - P_c) + \gamma}. \quad [20]$$

This equation would underestimate the effects of γ, especially for low probability words.

Rubenstein and Pollack (1963) provide data against which some of the implications of these equations can be tested. They presented their *S*s with a context: an incomplete sentence, a word to be associated to, a category name, or the first 1–5 letters of the target word. Each *S* made a response to the context ("the word they thought most likely to occur") and then was presented with the stimulus word at six increasingly favorable S/N, making a response following each presentation. Rubenstein and Pollack present data in two forms, the average proportion of correct responses for the whole group and the proportion for those *S*s who made an initially "incorrect" response to a particular context, which we may call the γ-minus group. When the performance for the γ-plus group is estimated from the data it is apparent that they made very few errors even at the lowest S/N, as would be expected from the above analysis. The performance of the γ-minus group is considerably worse, and at the lowest S/N their performance is worse than that of the whole group prior to the first stimulus presentation. The relevant data are given in Table 4.

TABLE 4

DATA FROM RUBENSTEIN AND POLLACK (1964) FOR A SENTENCE CONTEXT WITH S/N OF $-$14db.

Group	Performance							
P_c	.02	.11	.20	.26	.35	.47	.68	.84
P_{sc}								
γ-plus (E)	1.00	.92	.70	.99	.97	.94	.97	.95
γ-minus (F)	.02	.10	.15	.14	.20	.24	.25	.37

Note.—Data given were the overall probability correct (Q), the probability correct for the γ-minus group (F), and P_c. The γ-plus score (E) was estimated from $Q = P_c \cdot E + (1 - P_c)F$, whence $E = [Q - (1 - P_c)F]/P_c$.

From Equation 20 it seems likely that, with a few more assumptions concerning the effects of sequential presentation, the effects of increasing the S/N will be independent of the value of P_c, provided that the set of possible responses remains approximately orthogonal with regard to their stimulus properties. The results for the sentence context are presented in Figure 7. The ordinate represents the difference in logit P_{sc} between the $-$14db. condition and the parameter level; that is, effectively, the result of increasing the signal level from $-$14 db. to the given level. It is apparent that there is no systematic change. In contrast the data for the letter context are given. In this condition the context provides information which is highly correlated with the information available in the stimulus. In other words the resulting set of possible response words will be more highly confusable on average, the larger the number of letters context. Thus we would predict that the value of α would fall, the greater the number of context letters. This follows from the operational definition of α as the difference between the amount of information available from the stimulus to the correct logogen compared with the average for all other relevant logogens. This predicted trend is clear in the data.

Interaction of Successive Presentations

One property of the Logogen System which has not been discussed is the suggestion that stimulus information is only effective for a relatively short period after presentation. Thus we would expect no interaction between successive presentations of the stimulus, unless they followed in very quick succession. Various studies may be cited in support of this contention.

Postman and Adis-Castro (1957) compared performance on word recognition with the method of ascending limits and the method of random series whereby all the words were presented for recognition at each duration before proceeding to the next level. They found no significant difference between the conditions. Pollack (1964) investigated the interaction of visual and auditory information in word identification. He discovered that successive presentations of a stimulus word visually and auditorily gave rise to only 2% more correct responses on the second modality than would have been expected from the statistical independence model. He further points out that if partially correct responses were credited, even this 2% difference would vanish. This result effectively says that if S identified the word from the first modality, he identified it from the second one (owing to the operation of the γ-effect); if he did not recognize the word on the first modality, the probability of a correct identification on the second modality was the same as it would have been if the first modality had not been presented.

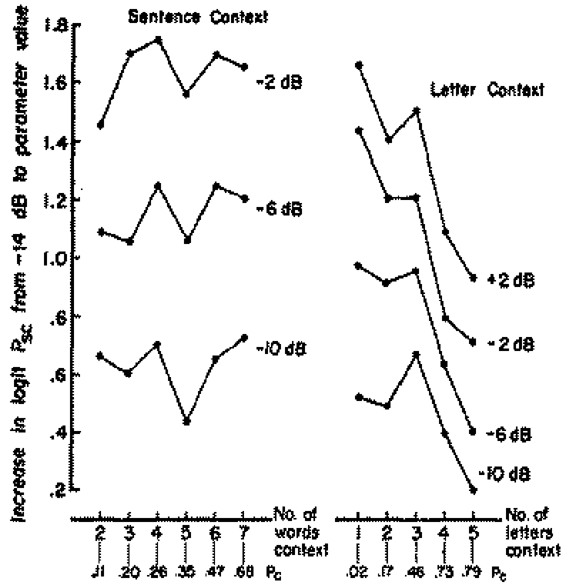

FIG. 7. Data from Rubenstein and Pollack (1963), showing the difference in the value of logit P_{sc} between the parameter S/N and -14db. for two kinds of contexts. (With the sentence context the effect of increasing the S/N is independent of the extent to which the context predicts the stimulus word. With a context of the first 1–5 letters, the effect of the stimulus is less the more the context owing to the correlation between contextual and stimulus information.)

Pollack's technique was to present the stimulus word once in one modality and then six times in the other modality under increasingly favorable conditions. He remarks that "Control tests were carried out to ensure that the successive ascending procedure was unbiased with respect to independent presentations [1964, p. 78]," essentially confirming Postman and Adis Castro, and while he quotes no data to support the statement, the main result is justification in itself.

Now it is clear to anyone who has examined the successive responses of individual Ss in an experiment using the ascending method of limits that there are dependencies in successive responses, particularly in that incorrect responses often influence subsequent responses (Morton, 1964a). It is also clear to anyone who has been an S under such a procedure that if, for example, on the first presentation the beginning of the word has been seen clearly, one can profitably concentrate attention on the end of the word on the next presentation. What must not be forgotten, however, is that such partial evidence can be incorrect as well as correct. If it is incorrect, then subsequent recognition will be hampered, as apparently occurred with Rubenstein and Pollack's γ-minus *S*s. What the experimental data show, then, is that these two competing effects tend to balance out over the course of an experiment. From this analysis we would predict that if *S*s were informed whether or not their partial responses were correct their performance should improve on subsequent trials, since, it can be assumed, the incorrect information, sustained as it is in the present model by some system equivalent to the Context System, would not be passed to the Logogen System. Such a result was found by Pollack, Rubenstein, and Decker (1959).

In summary, it is apparent that a complete description of the processes contributing to the effects of repeated presentation and the prediction of performance will require detailed consideration of partial responses as well as full responses. Gross probabilistic predictions ignore elements of the experimental situation which are clearly important.

CONCLUSIONS

The model under discussion was originally devised for qualitative reasons; in this paper quantitative predictions have been made about *S*s' behavior in a variety of situations. Although the model is idealized in ways which have been discussed, the data do not seem to contradict it. At the moment there is a lack of alternative functional models against which the Logogen Model can be tested. Purely mathematical models have been ignored because, as we have seen, it is relatively simple to add an extra parameter, albeit intuitively justified as a variable, which can produce a perfect fit to the data. Such a practice has not been indulged in since there are several factors with equal claim for inclusion whose quantitative effect cannot at the moment be estimated outside the data they would be accounting for.

The existing model has much in common with one recently put forward by Norman (1968). One difference hinges on the respective treatments of memory. Norman first points out that it seems necessary to distinguish between two forms of memory which correspond, respectively, to our immediate memories of events and memories of events a few seconds old. Norman follows William James in calling these types "primary" and "secondary," but makes the unnecessary assumption that the primary memory must precede secondary memory in the processing system, an assumption carried over from Waugh and Norman (1965). In the recent paper Norman argues that "there must be sufficient interconnections between the storages to allow a comparison of the just-perceived sensory events with the collection of previously experienced perceptions [pp. 524–525]". In fact, then, the two systems become effectively a single system with two types of storage within it.

The Logogen Model does not suffer from these objections for we can say that the Primary Memory is located in the Output Buffer which follows the Logogen System. Traces remaining in logogens, either in the values of the count or the threshold, could then be regarded as two possible sources of information (with different time characteristics) for Secondary Memory. The properties of these two stores, derived as they are for reasons other than memoric, match fairly well the usual characterizations of Primary and Secondary Memory.

The Output Buffer, which manifests itself in the eye-voice span (Morton, 1964b) and the ear-voice span (Treisman & Geffin, 1967) is seen as having a limited capacity, as is primary memory. Material within it is coded in terms of articulation parameters (since the usual destination of the material is speech). Thus we would expect to find articulatory confusions in Immediate Recall for visual stimuli, which task may be taken as involving primary memory. Conrad (1964) has shown that errors in recall of visually presented letters are highly correlated with errors made in recognition of letter names presented auditorily in noise. Conrad terms these "acoustic confusions" but the correlation between acoustic and articulatory descriptions leaves open the possibility that the correct description is "articulatory confusions."

The Logogen System, on the other hand, like secondary memory, is not subject to overwriting insofar as the γ-effect is concerned. It would, however, be impossible, from the state of the appropriate logogen, to discover whether or not a stimulus had been presented once or twice. Crowder (in press) has shown that lists of letters or words containing repeated items are more difficult than those without repeats. Such information as is retrieved concerning repeats would be available either in the Output Buffer or in a long-term memory store. The latter construct is necessary to account for our ability to maintain the effect of a context, and could well account for such associative phenomena as are demonstrated in memory tasks.

It is of interest that the present model, derived to account for phenomena of word recognition, requires at least three constructs, each with different properties, from which information could be retrieved in a memory experiment. Arguments based on parsimony as to whether there are one or two separate memory stores (Atkinson & Schiffrin, 1967; Melton, 1963) tend to lose their force. It might be more profitable for future work on memory to concentrate on attempting to specify the relative contributions of these different information sources in different experimental conditions.[7]

The differences in detailed treatment of memory between Norman's model and the Logogen Model are almost trivial and are certainly reconcilable. Of more interest are the similarities between the models. The core of Norman's model is a storage system into which sensory inputs and "pertinence" inputs are sent. The elements of the storage system are almost identical to logogens in their properties. Further, the sensory analysis systems in both models are conceived of as passive, or autonomous. Although Norman refers to his model as a modified analysis-by-synthesis model, the synthesis is in terms of "expectations," and as such takes a different form from other analysis-by-synthesis systems which require that the synthesized anticipation is in the same code as the input. Norman's model also provides a framework within which problems of attention and the retrieval of information can be discussed, neither of which topics the Logogen Model is capable of handling in its present form. Thus the two models can be seen as complementary to one another.

Perhaps the most important similarity is a strategic one. Both the models are capable of expansion to deal with phenomena outside the areas for which they were evolved without losing their essential character and without becoming too rigid.

[7] R. G. Crowder and J. Morton. Precategorical acoustic storage. Unpublished manuscript, 1968.

REFERENCES

ATKINSON, R. T., & SHIFFRIN, R. M. Human memory: A proposed system and its control processes. *Technical Report No. 110*, Institute for Mathematical Studies in the Social Sciences, Stanford University, 1967.

BROADBENT, D. E. Word frequency effect and response bias. *Psychological Review*, 1967, **74**, 1–15.

BROWN, C. R., & RUBENSTEIN, H. Test of response bias explanation of word-frequency effect. *Science*, 1961, **133**, 280–281.

CONRAD, R. Acoustic confusions in immediate memory. *British Journal of Psychology*, 1964, **55**, 75–84.

CROWDER, R. G. Intraserial repetition effects in immediate memory. *Journal of Verbal Learning and Verbal Behavior*, in press.

ERIKSEN, C. W., & BROWNE, C. T. An experimental and theoretical analysis of perceptual defence. *Journal of Abnormal and Social Psychology*, 1956, **52**, 224–230.

GARNER, W. R. *Uncertainty and structure as psychological concepts*. New York: Wiley, 1962.

GREEN, D. M., & BIRDSALL, T. G. The effect of vocabulary size on articulation score. University of Michigan: *Electronic Defence Group, Technical Memorandum No. 81 and Technical Note AFCRC-TR-57-58*, 1958. (Reprinted in J. A. Swets, Ed., *Signal detection and recognition by human observers*. New York: Wiley, 1964.)

GREEN, D. M., & SWETS, J. A. *Signal detection theory and psychophysics*. New York: Wiley, 1966.

LUCE, D. *Individual choice behavior*. New York: Wiley, 1959.

MELTON, A. Implications of short-term memory for a general theory of memory. *Journal of*

Verbal Learning and Verbal Behavior, 1963, **2**, 1–21.

MILLER, G. A., HEISE, G. A., & LICHTEN, W. The intelligibility of speech as a function of the context of the test materials. *Journal of Experimental Psychology*, 1951, **41**, 329–335.

MILLER, N. E., & DOLLARD, J. C. *Social learning and imitation*. New Haven: Yale University Press, 1941.

MORTON, J. The effects of context on the visual duration threshold for words. *British Journal of Psychology*, 1964, **55**, 165–180. (a)

MORTON, J. The effects of context upon speed of reading, eye-movements and eye-voice span. *Quarterly Journal of Experimental Psychology*, 1964, **16**, 340–354. (b)

MORTON, J. A model for continuous language behavior. *Language and Speech*, 1964, **7**, 40–70. (c)

MORTON, J. A preliminary functional model for language behavior. *International Audiology*, 1964, **3**, 216–225. (Reprinted in R. C. Oldfield & J. C. Marshall, Eds. *Language*. London: Penguin Books, 1968). (d)

MORTON, J. A retest of the response bias explanation of the word frequency threshold effect. *British Journal of Mathematical and Statistical Psychology*, 1968, **21**, 21–33. (a)

MORTON, J. Grammar and computation in language behavior. *Progress Report No. 6*, Center for Research in Language and Language Behavior, University of Michigan, May 1968. (b)

MORTON, J., & BROADBENT, D. E. Passive vs. active recognition models or Is your homunculus really necessary? In W. Wathen-Dunn (Ed.), *Models for the perception of speech and visual form*. Cambridge, Mass.: M. I. T. Press, 1967.

NORMAN, D. A. Toward a theory of memory and attention. *Psychological Review*, 1968, **75**, 522–536.

POLLACK, I. Interaction between auditory and visual information sources in word identification. *Language and Speech*, 1964, **7**, 76–83.

POLLACK, I., RUBENSTEIN, H., & DECKER, L. Intelligibility of known and unknown message sets. *Journal of the Acoustical Society of America*, 1959, **31**, 273–279.

POSTMAN, L., & ADIS-CASTRO, G. Psychophysical methods in the study of word recognition. *Science*, 1957, **125**, 193–194.

RUBENSTEIN, H., & POLLACK, I. Word predictability and intelligibility. *Journal of Verbal Learning and Verbal Behavior*, 1963, **2**, 147–158.

STOWE, A. N., HARRIS, W. P., & HAMPTON, D. B. Signal and context components of word-recognition behavior. *Journal of the Acoustical Society of America*, 1963, **35**, 639–644.

TREISMAN, A. M., & GEFFIN, G. Selective attention: Perception or response? *Quarterly Journal of Experimental Psychology*, 1967, **19**, 1–16.

TULVING, E., MANDLER, G., & BAUMAL, R. Interaction of two sources of information in tachistoscopic word recognition. *Canadian Journal of Psychology*, 1964, **18**, 62–71.

TULVING, E., & PEARLSTONE, Z. Availability versus accessibility of information in memory for words. *Journal of Verbal Learning and Verbal Behavior*, 1966, **5**, 381–391.

WAUGH, N. C., & NORMAN, D. A. Primary memory. *Psychological Review*, 1965, **72**, 89–104.

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