A MODEL FOR CONTINUOUS LANGUAGE BEHAVIOUR*

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The errors made in reading passages of statistical approximations were analysed. They fell into categories of omissions, substitutions and errors showing the influence of preceding words and the influence of subsequent words (including errors of transposition). A relationship is shown between errors of transposition and omissions in such a way as to indicate that the material in the eye-voice span was subject to decay in a way similar to that described in some theories of immediate memory. Many of the errors due to effects of preceding words and certain of the substitutions and omissions are shown to be consistent with the transformational model for grammar due to Chomsky.

Since it can be shown mathematically and linguistically that natural language sequences cannot be treated fully by information theory, the concept of ' thought units ' is developed to explain functionally language behaviour which may be described statistically by information theory. These thought units are then linked with the ' kernel strings ' which are the core of Chomsky's grammar. Finally some suggestions are put forward relating this structure to problems of semantics, with particular reference to comprehension in reading.

INTRODUCTION

This paper is based upon an examination of the errors made in reading passages of statistical approximations to English. In the original experiment (Morton, 1964a), undergraduate and senior members of Reading University were required to read aloud 200-word passages of zero- to sixth-order inclusive, of eighth-order approximations, and a 430-word passage of prose. Parts of some of the passages were taken from Taylor and Moray (1960). The instructions were to " read as quickly as possible, minimising errors ". Speed of reading increased up to the fifth or sixth order.

While the subjects read, their eye-movements were recorded electrically through a two-channel pen recorder. The output from a speech microphone was recorded on the other channel, enabling the eye-voice span to be measured. This span, the amount of material already seen but not yet spoken, increased up to the eighth order of approximation.

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The treatment of the errors made in reading derives from the assumption that errors do not just happen, but are caused. The errors fall naturally into certain categories, some of which are similar to the errors found in a previous experiment (Morton 1964b).

In the latter study, henceforth referred to as the *threshold experiment,* measurements were made of the visual duration threshold of words flashed on a screen either with a sentence context which the word completed, or with no context. The errors made by subjects here could be classified into three main groups. These showed the effects of :

1. Expectancy: a word was sometimes reported as being perceived which occurred at a higher probability in the context than the word exposed.
2. Previous stimuli or responses : a word previously occurring as a stimulus or as an incorrect response was often later reported as being perceived.
3. Word shape : a large proportion of the errors made were of words with some element in common with the stimulus word. These were length or position of the ascenders (*t, d, h,* etc.) or descenders (*g, p,* etc.) or some combination of these.

The main finding was a relationship between the *visual duration threshold* of the words and their probability in the context (transitional probability). In a model derived to account for this result and the errors (Morton, 1961, 1964a, c), a ' unit ' is postulated which represents each word. In the model, the threshold of the unit is lowered by the operation of the *sequential processes* which mediate between a context and any word evoked by the context. The unit's threshold is also lowered by incoming sensory information which has been processed to extract visual cues such as shape. When a unit fires, the corresponding word is available as a response. This may happen with or without incoming sensory information ; i.e. in a recognition or a generation situation.

In the present paper, errors will be found similar to those described above, but there are additional categories of error peculiar to a continuous task. These categories suggest various possible mechanisms involved in the reading process. In some cases these mechanisms are extensions of the model already described.

In many cases an error may be classified and quoted under more than one heading, and in other cases an error will violate the principle of one of the mechanisms. It is not considered that the presence of such factors invalidates the approach, since the mechanisms are regarded as probabilistic and not absolute in their operation. They can act together or in opposition in determining a response.

The present treatment demonstrates especially the influence of previous words and phrases in determining the errors made in reading. The unusual nature of the passages has possibly accentuated this kind of error, in that errors can result from a discrepancy between a word in a passage and the word or words which would normally appear in the context.

In the classification that follows, corrected and uncorrected errors are treated together. In the examples quoted, the correct word or phrase is given first, and the response to it follows. Each example is preceded by a passage and line reference.

Thus :

4 L9 — indicates that the word or phrase can be located in the ninth line of the fourth order passage.
t L17-18 — the seventeenth and eighteenth lines of the text.

The passages are given in the Appendix.

A number following an example indicates the number of subjects who made the error if it occurred more than once. A number followed by ' c ' indicates the number of times the error was made and corrected. Thus :

(4 + 2c) — four subjects made the error without correcting it and an additional two subjects made the error and then corrected it.

Two other symbols are used :

/ — indicates a pause in the reading. This is usually followed by a correction of the error.
... — indicates that the subject continued correctly, or indicates a correct reading within the phrase quoted.

The italicising of words in the examples quoted is intended to make it easier to see the origin of the error. Which words are in italics depends upon the error category. (N= —) indicates the number of uncorrected errors in the category.

The Errors

Effects of preceding words

Syntactic Effects

(a) *Without previous error*

This subdivision of error is mainly due to the abnormal nature of the approximation passages. These passages violate normal rules of syntax, and there was a tendency for subjects to make errors by maintaining grammatical continuity.

(i) Verbs altered or nouns read as verbs to agree with a preceding noun or pronoun (see also Table 1, i). (N = 10)

1 L13 : *he* way become — *became* (4 + 1c)

(ii) Verbs altered to agree with a preceding verb (see also Table 1, ii). (N = 33)

3 L7 : *danced* all night and day come — *came* (9 + 1c)
— *gone*

In 6 L15, *come* occurs with *gives* as the preceding verb ; it was never read as *came*. This kind of control does not often occur and serves to justify the assumption that the error is attributable to the presence of a preceding verb in the past tense.

TABLE 1

Examples of syntactic errors

(i) Verbs altered or nouns read as verbs to agree with a preceding noun or pronoun.
1 L3 : I *heart* — I *hurt*
1 L10 : are we marriage — are we married
3 L11 : *labels* on his bicycle was — *were*

(ii) Verbs altered to agree with preceding verbs.
5 L5-6 : he *chose* to go home if they don't — *didn't*
t L6 : If . . . you *wanted* — want (' If you *want* ' occurs in line 1)
8 L11-13 : committing . . . regarding . . . taking . . . and removed — removing (4 + 1c)
8 L11-14 : (influence as above) . . . gathered — gathering

NOTE : On two other occasions a participle was substituted for an inflected verb :
3 L10 : started — starting
4 L2 : sing — singing

The etiology of these errors is discussed under LINE ERRORS (p. 52) and in Table 4(b) (p. 46) respectively.

(iii) Personal pronouns substituted or inserted which agree with a previous noun or pronoun (see also Table 2). (N = 17)

2 L12 : *her* hand and he was — *she* was (2)
2 L2 : *men* only when seen again — when *they* see again

Seven cases of pronoun error did not fall into this category but are included in other categories, two could not be categorized. Many of these errors are also repetition errors (see p. 46).

TABLE 2

Examples of syntactic errors

Personal pronouns substituted or inserted which agree with a preceding noun or pronoun

2 L6 : *uncle* can travel in case you — . . . in case *he*
3 L6-7 : *Charlie-boy* who was there as we danced — as *he* danced
3 L7 : (influence as above) . . . come with my friend — *his* friend
3 L8 : *I* am convinced that they — that *we* (changed to 1st person)
4 L9-10 : *her* toe touched *her* head I placed on — I placed *her* on
4 L11 : (influence as above) and then went — and then *she* went
4 L11 : (influence as above) yesterday to buy — yesterday *she* . . .
4 L11-12 : *Jennifer* on *her* knee . . . went his — . . . went *her*
5 L4-5 : when *they* reached home then the man — . . . then *their* man
— . . . then *they* man
5 L8-9 : a *man* who was . . . which led to — which led *him* to
5 L13 : *I* hope to dig — I hope *I* dig
6 L13-14 : *unions* . . . *their* course . . .
. . . I believe that she — that *they* (1c)
8 L1 : *I* thought of asking if he could — if *I* could (1 + 1c)

(b) *With previous error* (see also Table 3). (N = 31)

Occasionally an error of substitution, insertion or omission would alter the structure of a phrase in such a way that a further error would have to be made to maintain the syntax. These dependent errors were made in all but one case. Such errors were never detected.

2 L2 : when seen — when they see
5 L3 : coffee cup — cup of coffee

In the last example, the transposition of *coffee* required the insertion of *of* if the flow was to be maintained.

The exception was :

6 L15 : who gives — who can gives.

TABLE 3

Syntactic errors

Examples of errors made to agree with a previous error

5 L4 : leg was — legs were
5 L5 : the man took off his overcoat — the men took off their overcoats
8 L6 : he recovered — he could recover
t L2 : you look for work — you must go work/go and work
t L12 : Let us take first the type of — Let us take the first of the type of
t L19 : from a large central warehouse — from large central warehouses (4)
t L20 : go long distances — go a long distance

Semantic Effects

Two errors involved the substitution of a word which was semantically associated with previous words, and very similar in form to the word which it replaced.

4 L9-10 : her toe touched her *head* . . . and figures — *fingers* (1 + 1c)
8 L1-2 : *enquiry* I thought of *asking* . . . everlasting renown — everlasting *reason* (1c)

Influence of Previous Responses

In the threshold experiment, a class of errors was noted which showed the influence of responses on subsequent responses, involving the repetition of whole words or parts of words. Similar effects are found in the reading task, resulting in errors of insertion and substitution (see also Table 4).

(a) *Word Repetition* (N = 12)
1 L1 : *had* into of turn — had into *had* of turn

(b) *Influence of parts of words* (N = 12)
0 L2 : *para*clete papulose — paraclete *para*pluse

(c) *Repetition of an incorrect or partial response*
1 L1 : into of turn head — into *the* he-/into *the* turn head
1 L13 : the too he way — the *w*-/too *way*/he way
1 L14 : all Labour local — all *lo*-/Labour *lo*-/local
2 L5 : philosophy many an every cat — philosophy *ca*-/many an every day/*ca* -eee/cat

In the last error the ' eee ' was an expression of mortification rather than an incorrect response. It is interesting to note that another subject made the corrected error *day/cat*.

4 L6 : without blood flowing — without *flo*-/blood *flo*-/flowing.

TABLE 4

Influence of previous responses — Repetitions

(a) *Word repetition*

2 L2 : seen *again* and then it — seen again and *again* it
2 L8 : *for* fun is young — for fun is *for* young
2 L11 : *two* dirty and so quickly — two dirty and *two* (too ?)/so quickly
3 L6 : around *so*mething to do nothing — . . . to do *so-*/nothing
4 L6 : killed *him* without blood — killed him without *him*/blood . . .
4 L9-10 : *her* head I placed on — her head I placed *her* on
5 L14-15 : *today* . . . *today* . . . seen to be — seen *today*
5 L15 : *who are* to be seen to be — who are to be seen *who are* to be
6 L11 : *just* caught the thief when the alarm — . . . the thief when then *just* as the alarm
t L1-2 : you *must* go . . . you look — you *must* look (4)
t L2-3 : *in* Sheffield . . . the West Country and Scotland — in the West Country . . . — in Scotland
t L7-8 : *in* practically any locality — in practically *in* any . . .
t L26 : houses *built* of brick must necessarily be erected — . . . be *built*

(b) *Influence of Parts of Words*

0 L7 : excellen*cy* poignantly — excellency poignan*ce* (2) — excellency poignanc*y*
4 L2 : even*ing* people sing — sing*ing*
4 L6 : without *blo*od flowing — without blow *blow-*/flowing
8 L6 : contage*ous* and infections — infecti*ous* (4 + 1c)
8 L9 : headl*ong* under — headlong al*ong*

EFFECTS OF SUBSEQUENT WORDS

Effects involving whole words

There were many examples of errors arising from a word being misplaced.

(a) *Transposition of adjacent words* (see also Table 5). (N = 37)

The most frequent example was :

t L3 : you would *have rather* more choice — you would rather *have* . . . (5 + 1c)

Occasionally the transposed word was repeated in its correct place (N = 9) :

1 L6 : be *from or* — be *or from* or

Transposition errors were often corrected (N = 34) :

4 L10-11 : began and then went to London — began then/and then went Lon-/to London.

TABLE 5

Errors involving adjacent word transposition

(i) *Examples of single transpositions*

NOTE : the pair of words quoted were transposed.

1	L1 : of turn (2)	4	L4 : middle hole
	L9 : its all		L4 : often might
	L10 : are we (2)		L4 : badly needs
	L12 : of dominate		L6 : when it
	L13 : to children		L8 : were all
	L13 : the to		L11 : and then (1 + 1c)
			L12 : town to
2	L2 : again and		L12 : down went
	L5 : philosophy many		
	L9 : hoping desperately	5	L11 : in duplicated
	L9 : will you		
	L10 : is it (2)	8	L4 : with it
	L10 : without care		
	L12 : from here	t	L3 : have rather (5 + 1c)
			L9 : are some
3	L1 : to try (1 + 1c)		L12 : first the
	L7 : was there		

(ii) *Examples where the transposed word was repeated*

1 L6 : be from or — be or from or

2 L3 : there is cabbage a horse — there is a cabbage a horse (5 + 2c)

4 L12 : walked down town to the — walked down to town to the

t L12 : take first the type — take the first of the type

(b) *Misplacement of two words* (this could be described as a single word delayed by two places) : there was only one example of this error :

5 L7 : gate-post *and* opened it deliberately — gate-post opened it *and* deliberately

TABLE 6

Misplacement of a single word by more than one position

(i) *Where the displaced word is repeated in its correct place*

1 L1 : had into of *turn* — had *turn* into of turn
2 L9 : and it hell it *is* — and it *is* hell it is (3 + 2c)
2 L14 : with flowers with *the* public — with *the* flowers . . . (2)
t L1 : you know that you *must* go — you *must* know . . . (2)
t L5 : look first somewhere *in* — look *in* first . . .

(ii) *Where the error was corrected*

1 L1 : into of turn *head* — into the *he-*/into the turn head
(also substitution of ' the ' for ' of ', an error retained in the correction of the misplacement)
1 L13 : he the too he *way* — he the *w-*/too way/he way
2 L5 : philosophy many an every *cat* — philosophy *ca-*/many an . .
4 L10-11 : began and then *went* — began *w-*/and then went
5 L2 : two bottles of *brown* ale — two *browns*/bottles . . .
5 L14 : today however it *will* — today *w-*/however it will
5 L15 : publishers who are to be seen to be
— publishers to be seen/who are to . . .
— publishers who are see/be/to be seen . . .
— publishers who are seen/who are to be . . .
8 L2 : could hope to *win* — could *wi-*/hope to win
8 L10 : garden began decaying *from* — garden *fro-*/began decaying . . .
8 L12 : matter seriously and *conscientiously* — matter consci-/seriously . . .
t L25 : before the second world *war* — before the *wa-*/second world war
t L31 : so that even *if* it — so *if* there/so that even
t L33 : would still be more widely — would wide-/still be . . .
t L15-16 : domestic service and hairdressing — domestic hair-/service and . . .

(iii) *Where the displaced word is substituted for another word*

6 L15 : comfort so come *but* — comfort *but* come/so come but
8 L15 : he decided to *decline* — he *declined* to decline
t L18-19 : are sent by post *to* — are sent *to* post to (2)

(c) *Misplacement of a single word by more than one position* (N = 14) (see also Table 6); it was possible for a word to be given as a response as many as four places before its correct position. These errors could be sub-classified as follows :

(i) Where the displaced word was repeated in its correct place.
5 L9 : led to a path beside *him* — led *him* to a path beside him.

(ii) Where the error was corrected.
t L32 : in prefabs than in *brick* houses — in *bri-*/prefabs . . .

(iii) Where the displaced word is substituted for another word, and repeated in its correct place.
2 L9 : and it hell it *is* — and *is* hell it is

(iv) Where the displaced word is not repeated.
3 L6 : round something to do *nothing* about — round *noth-*/something to do about
t L8 : the siting of businesses — the business of employers (!)

Effects involving parts of words (N = 28)

We have noted certain effects of previous responses involving parts of words (see Table 4b). Similar effects are found involving the influence of parts of subsequent words (see also Table 7). These errors may or may not have been corrected.

1 L3 : h*all* could — *call*/hall could
2 L6 : *m*ay y*et* — *met* yet

TABLE 7

Influence of parts of subsequent words

2 L4 : *round* about — *around* about (5)
2 L8 : happ*ily* *mar*ried — marrily/happily married
4 L8 : *rich*er quick*ly* — *richly* quickly
6 L7 : *given* by one man stand*ing* — giving by one man standing/given by . . .
6 L15-16 : but do i*t* *now* — but do not now/do it now
8 L15 : *decided* to *decl*ine — *declide*/decided to decline
8 L8 : fresh br*eezes* *bl*owing — fresh *blee-*/breezes . . .
8 L11 : an am*using* *off*ence — an *affusing*/amusing offence

Omissions

Words were omitted on 189 occasions, thus accounting for 22% of all errors made. Such errors are clearly related to errors of transposition. Consider the words " all Labour local order ", (1, L14). Two errors, subsequently corrected ,were made in reading these words :

(i) all local La-/Labour local order
(ii) all local/Labour local order

We can see quite clearly that (i) is a correction of a simple transposition error, and it seems fairly obvious to regard (ii) in a similar way. However, it is not possible to say whether the subject was about to say " all local Labour order "—a transposition error, or " all local order "—an omission error.

Such corrected errors have been classified with transposition errors. A possible explanation of these two types of error, involving a single mechanism, will be given in a later section. The most frequent omission errors were as follows (see also Table 8) :

2 L3 : be *the* set — be set (5)
t L27 : experience has *now* shown — experience has shown (4)

All classes of words were about equally frequently omitted, except for nouns and main verbs which together accounted for only 14 omissions. In these cases there was usually some restructuring of the phrase or subsequent dependent error.

e.g. 4 L1 : the boy went to *eat* fish — the boy went to fish (" fish " becomes a verb).

With the text passage especially, where omissions accounted for about 30% of the total number of errors, the omitted words were often completely redundant, and in many cases the omission made no difference to the flow of the passage.

Table 8

Examples of omissions — the word in brackets was omitted

1 L13 : he (the) too (3)
2 L3 : be (the) set (5)
t L3 : you (would) have (3)
t L12 : type of jobs (that) you (3)
t L14 : and, (as) they must be (5)
t L14 : necessarily (as) dispersed (3)
t L27 : experience has (now) shown (4)
t L30-31 : connect water (and) drainage (3)
t L31 : must (still) be (3)

ERRORS OF SUBSTITUTION

Excluding the errors of substitution already noted, which could be attributed to a direct influence of preceding or subsequent words, a total of 307 errors of substitution were made. (This also excludes the zero order passage which is considered separately.) These errors were classified into the categories of *suffix* or *prefix alteration, functional similarity, structural similarity* and *other errors*. Many errors fell into more than one category ; when this occurred, they were classified in the first applicable category in the above list.

(a) *Suffix or Prefix Alteration*

A total of 75 errors involved the change, omission or insertion of a suffix. The most common such error involved the letter *s* which was added on 17 occasions and omitted on 22 occasions. The addition of an *s* was particularly prone to occur if an adjacent word had a final *s*.

4 L5 : eat lots — eats lots (13 + 1c)

All these errors involved maintaining the root of the word and changing the original word to another part of speech, or to another number in the case of nouns, or tense or number in the case of verbs.

e.g. whilst — while (7) ; larger — large ; image — imagine ; Roman — Rome ; disappointment — disappointed ;

A further 13 errors involved changing, omitting or inserting a prefix or an initial letter.

e.g. view — review ; selection — election ; dominate — predominate.

(b) *Functional Equivalence*

For want of a better term, *functional equivalence* refers to those 133 errors in which functionally equivalent words, synonyms, or antonyms were substituted for the stimulus word. For example, relative pronouns, conjunctions and articles were changed, and *should, could* and *would* were interchanged 13 times ; other examples are :

evening — morning ; Sunday — Saturday ; this — the same ; slowly — straight away ; might — may ; most — many ; someone — somebody ; came — gone.

(c) *Structural Similarity*

These 68 errors are similar to the classes of perceptual error found in the threshold experiment. In all cases at least the initial and final letters of the response word correspond to the original word.

e.g. united — untied ; sacred — scared ; election — electron.

8 errors involved the inversion of a letter :

e.g. labels — lapels ; way — may ; coffee — coppee (1c) ; blue — prue.

(d) *Other errors of substitution*

Thirty errors did not fall into the above three categories. All but three of these were in the first or second order passages ; 15 of them tended to complete the structure of the containing phrase :

1 L7-8 : those found *such* reply — those found *in* reply
1 L13 : *the* to children — *as* to children
1 L14 : local order *then* without — local order *were* without

Only six reduced the structure.

Insertions

A total of 123 insertions were made. Articles were added 27 times : in the lower order approximations, to nouns without an article ; in third and higher orders, changing the indefinite phrase to the definite or to the singular, the latter examples leading to further errors. Verbs were added on 29 occasions, 24 of which involved adding an auxiliary verb. 44 errors involved inserting function words, only 6 examples of which were definitely deleterious to sense or syntax. Examples of this kind are :

4 L8 : so they were — so *that* they were (7)
6 L13 : so the unions — so *that* the unions (4)
t L26-27 : the site they are to occupy — the site *which* they are to occupy (3)

Line errors

Seventeen errors could be attributed to the intrusion of a word or part of a word on the line immediately above or below.

3 L10 : started — starting (*going* occurs on L9)
5 L4 : because when they reached — because he could reached
(*Because he chose* occurs just below on L5)
8 L11 : war — water (*water* occurs on L10)
t L1-2 : you must go to Lancashire — you must go to She-/Lancashire (2c)
(*Sheffield* occurs at the end of L2).

The errors in the zero order passage have been excluded from the above analysis since so many of the words were unfamiliar and complicated, and the conditions of reading were thus excessively abnormal. The unfamiliar words were often mangled. Thus *atrabiliar* was variously rendered as :

atribiliar ; atrabular ; atribliar ; atriliabliar ; atrabilar.

The consequence of the presence of such words was to make some subjects attempt

to read the words syllable by syllable. This led to other errors of pronunciation of familiar words. Thus :

ration — raytion (3c)
— ray-/ration (6c).

THE RELATION BETWEEN ERRORS OF TRANSPOSITION AND OMISSION

(a) *The Effects of Delay*

Any word which is transposed backwards in reading must be within the eye-voice span. Such errors have been found involving the fourth or fifth word in the span ; only rarely was the span greater than this. It seems reasonable then to regard all the material in the span as being available as responses. The order in which these words emerge as responses will normally correspond with the order on the page. This could be due, for example, to either or both of the following :

(1) Response dependencies—a function of the sequential processes which determine the probability of a word in a context.

(2) Some labelling of the stimuli with respect to order (cf. Crossman, 1961).

If the influence of response dependencies or the system of labelling breaks down, or is insufficient, the responses may be made in the wrong order.

The items which have been identified but not yet given as responses are clearly in a similar condition to the items being remembered in an immediate memory experiment. The analogy is strengthened when one considers the explanatory value of the *decay theory* of immediate memory (e.g., Brown, 1955, 1958) in relation to certain categories of error.

> " The basic hypothesis of this theory is that when something is perceived, a memory trace is established which decays rapidly during the initial phase of its career. (By memory trace is meant only the neural substrate of retention, whatever this may be.) Some decay of the trace is assumed to be compatible with reliable recall—just as partial fading of print may be compatible with perfect legibility. But recall will cease to be reliable if decay of the trace proceeds beyond a critical value." (Brown, 1958, p. 12).

According to this theory then, the longer such a memory trace has been in existence, the less reliable will be the recall. If the response of a particular word is delayed beyond a certain period, the word will be forgotten. The effect of transposing a word would be to delay the response of the next word : *a b c d* — *a b d c* (where *a . . . d* represent words). If two successive words are transposed, the next word would be delayed even more (*a b c d* — *a c d b*). Therefore the more words which are transposed in front of a given word, the less likely it is that the word will be recalled at all, and the more likely will be an error of omission. In this way, a sub-class of errors of omission could be regarded as a consequence of the phenomenon of transposition.

Thus we would predict more frequent occurrences of *transposition* errors where one word is transposed, than when a pair of words is transposed, since in the latter case the delayed word would be more likely to be forgotten and an *omission* occur. In fact there are 80 cases of the former error, and only the single quoted case of the latter.

(b) *The Effects of the Sequential Processes*

Consider the situation when the sequence *a b c d e* was in store, and *a c* has been spoken. The relative likelihood of *b* or *d* occurring as the next response clearly depends upon the precise nature of the mechanisms determining the next response, but the influence of the sequential processes will be in favour of *d*. If *a c d* has been spoken, then this influence will be even more strongly in favour of *e* compared with *b*. This effect would reinforce the effects due to the decay of the trace.

The effect of the sequential processes may be further illustrated. Consider the sequences of responses *a b d c* and *a d b c*. The most probable responses to follow are clearly *d* and *e*. Assuming that the making of a response does not accelerate the decay of the trace (the existence of repetitions seems to justify this assumption), the relative amounts of decay of *d* and *e* are the same in both sequences. However, the influence of the sequential processes in favour of *d* will be stronger in the second case, and we would predict that *d* would follow *a d b c* more often than it would follow *a b d c*. In other words we would expect a word transposed by more than one position to be repeated more often than a word transposed by only one position. Examination of the errors shows that of the 48 occurrences of the simple uncorrected transposition, the transposed word was repeated only on 9 occasions, 5 of those on the same example (see Table 5). On the other hand, all except one of the 14 uncorrected *a d b c* type of error resulted in the repetition of the transposed word (see Table 6).

(c) *Omissions and Pauses*

A number of omissions occurred immediately following a breath pause. It was predicted that such omissions would be caused by the absence of a regression of the eyes during the pause. In this way there would be an increased likelihood of the next word being lost through decay of the trace. Of the 26 omissions which followed pauses, only 6 were accompanied by regressions. For each of the remaining 20 omissions, the next three pauses in the record, unaccompanied by an omission, were examined to see if they were accompanied by regressions. Regressions were found in 57 of the 60 cases. Thus it is concluded that the absence of a regression during a pause does increase the likelihood of an omission.

It seems then that we are justified in regarding the material in the eye-voice span as being subject to decay. This material seems to be in the short term memory store, though there are apparently differences in the capacity of the store in the two cases, the immediate memory experiments showing a higher span for all orders of approximation (Morton, 1964a). However, in measuring the eye-voice span, we ignore any words in the store which have already been spoken, although the errors of repetition clearly show that such words are still available as responses.

THE INFLUENCE OF THE STRUCTURE OF LANGUAGE

In the model derived to account for the results of the threshold experiment attention was drawn to the correspondence between the recognition and generation situations in the conditions where, in the presence of a context, a single word is given as a response respectively either with or without visual cues. In addition it was found that the ease of perception of a word was correlated with a variable, transitional probability, which also appeared to influence the errors which were made (Morton, 1963b).

If the model is to have any generality, then we would expect there to be a similar correspondence between the equivalent situations involving *continuous* production and recognition of speech. In other words, it should be possible to point out some system which describes naturally generated language, which both operates to increase the ease of reading of successively higher orders of approximation, and influences the errors made in reading.

Now we can describe the difference between the orders of approximation in terms of the amount of context operating to determine any word, or simply, in terms of the mean predictability of the words in any passage. However, in spite of the fact that such terms as ' probability ', ' redundancy ' and so on, have been used to describe some of the effects which have been found, these terms are meaningless when it comes to describing atomistically the generation of language. Use of such terms usually implies that a sentence is a simple chain, with each word chosen on the basis of the previous ones.[1] This is not only subjectively unsatisfactory (we are usually aware of having some idea of the nature of what we are about to say before we know the actual words we are going to use), but is impossible both mathematically and linguistically. Mathematically, we see that from the estimates of the average information per word in English sentences, it would be necessary for a child to have experienced about 10^{30} different sentences before he could speak or understand English, which is impossible. Linguistically it can be shown that no grammar based on such a viewpoint could describe the language. If it produced all English sentences, it would also produce many non-sentences ; if it produced only English sentences, it could not produce all English sentences.[2] In addition, while it is possible to say that some of the errors produced more probable sequences, such errors have been classified with other errors of which this is not so ; the criterion for the classification being more specific than merely ' more probable ' or ' less probable '.

Although the notion of probability has been found of use as a statistical or descriptive

[1] *The extension of the argument to deal with estimates of the probability of a word embedded in a context is mathematically the same.*

[2] *These arguments are stated rigorously by Chomsky (1957, pp. 18-25) and Miller, Galanter and Pribram (1960, pp. 145-148).*

tool, we cannot fit it simply in to any model which hopes to describe the neural processes involved in reading. Thus we must find alternative ways of describing the difference between the orders of approximation. Two such ways are the semantic and the syntactic. The semantic differences—related to ' meaningfulness '—will be discussed briefly in a later section ; the syntactic aspects are of immediate interest.

The importance of considering syntactic structure, and the relation between the linguist and the psychologist in such a study have been well expressed by Chomsky (1959). He refers to the paper by Lashley (1951) and continues :

> " Lashley recognises, as anyone must who seriously considers the data, that the composition and production of an utterance is not simply a matter of stringing together a sequence of responses under the control of outside stimulation and intra-verbal association, and that the syntactic organisation of an utterance is not something directly represented in any simple way in the physical structure of the utterance itself. A variety of observations lead him to conclude that syntactic structure is a ' generalised pattern imposed on the specific acts as they occur ', and that ' a consideration of the structure of the sentence and other motor sequences will show . . . that there are, behind the overtly expressed sequences, a multiplicity of integrative processes which can only be inferred from the final results of their activity '. He also comments on the great difficulty of determining the ' selective mechanisms ' used in the actual construction of a particular utterance.
>
> Although present-day linguistics cannot provide a precise account of these integrative processes, imposed patterns, and selective mechanisms, it can at least set itself the problem of characterising them completely . . . it should be possible to derive from a properly formulated grammar a statement of the integrative processes and generalized patterns imposed on the specific acts that constitute an utterance. The rules of a grammar of the appropriate form can be subdivided into the two types, optional and obligatory ; only the latter must be applied in generating an utterance. The optional rules of the grammar can be viewed, then, as the selective mechanisms involved in the production of a particular utterance." (pp. 55-56).

Since we would predict that such mechanisms would be involved in a recognition situation as well, what is required is a description of language, in the form of a grammar, against which to compare the errors which have been found.

The grammar which will be considered is that due to Chomsky (1957), whose ideas are summarily set out in his monograph ' Syntactic Structures '. This work has been called " one of the first serious attempts on the part of a linguist to construct within the tradition of scientific theory-construction a comprehensive theory of language " (Lees, 1957, p. 377). This grammar describes the structure of the language in three stages. In the first place a series of basic sentences (' kernel strings ') are derived from a series of rules concerned with ' Phrase Structure '. Such sentences are simple, declarative, active and with no complex noun or verb phrases. All other sentences are derived from the kernel strings by means of ' transformations '. The third stage, in

the production of speech, is concerned with the morphophonemic rules by which the derived sentences may be uttered.

The derivation of a kernel string may be illustrated by first considering that a sentence S consists of a noun phrase, NP, and a verb phrase, VP. The rule which expresses the analysis may be written as :

(1) S → NP + VP

where the arrow indicates that we can rewrite S as NP + VP. Other rules concerning grammar and vocabulary could be :

(2) NP → T + N (where T and N are defined by rules 4 and 5 below)
(3) VP → Verb + NP
(4) T → the
(5) N → man, ball, etc.
(6) Verb → hit, took, etc.

From these rules we could derive such sentences as ' the ball hit the man ' and ' the man took the ball '. Other rules of formation which apply in phrase structure concern number in a noun phrase and possible inflections of the verb.

From these strings all other sentences are derived by rules of transformation. These include the transformation to negation, to the passive tense, and to the interrogative, a number transformation and rules for combining strings to make complex sentences. From such transformations we may derive sentences such as ' the men were not hit by the ball ' from the basic sentence.

Miller *et al.* (1960) comment :

> " With such a theory it should be possible to do a fairly good job of speaking English grammatically with less than 100 rules of formation, less than 100 transformations, and perhaps 100,000 rules of vocabulary and pronunciation. Even a child should be able to master that much with ten or fifteen years of practice " (pp. 152-3).

Before trying to transform such a theory[3] into some kind of quasineurological equivalent, we must note that Chomsky himself has pointed out that " The construction of a grammar . . . does not in itself provide an account of the behaviour (of the speaker) " (1959, p. 56). With this warning in mind, let us suppose that Chomsky's theories in some way represent the way in which speech is produced. We see that such a system is relatively simple (' simplicity ' is Chomsky's ultimate criterion for the evaluation of a grammar ; see especially 1957, pp. 49-56) as far as learning is concerned. If language is learned in this way ; if the rules of formation and transformation

[3] *The author is painfully aware that his account of Chomsky's theories is inadequate for all but the most elementary considerations. Miller et al. (1960, Chapter 11) gives a slightly more detailed summary of the theories, and detailed accounts may be found in Chomsky's monograph and the review by Lees (1957).*

have a neural equivalent, then it is necessary that on the neural level, as well as on the lexical level, there will be connections between any word and its inflected forms. This might be expressed in terms of the corresponding *units* (cf. the model described in the introduction), or to use Penfield's (1959) term, ' the ganglionic equivalent of a word ' (p. 230). In the generation of a sentence then, we might suppose that an idea is conceived in the form of the kernel string and the necessary transformations. The inflected form of any word would be synthesised via the ' kernel ' of the word.

While it is not necessary that the reverse process take place in recognition, it would be economical.

From a linguist's point of view :

> " . . . it would be a great step forward if it could be shown that all or most of what is ' meant ' by a sentence is contained in the kernel sentence from which it is derived. And much of the obscurity beclouding the idea of meaning may very well have resulted in large measure from a restrictive over-concern with lexical items and dictionary entries to the exclusion of the sentence, for while the former are seen in many but by no means all cases to participate in a relation of denotation or naming, it may be that it is only the latter unit, the sentence, which is truly significant, i.e. has a ' meaning '." Lees (1957, pp. 393-4).

If, in the process of recognition and of determining meaning, a sentence is analysed down to the kernel strings and the transformations by means of which the sentence could be derived, then certain predictions may be made as to the nature of the errors which might arise in reading. For example, the wrong transformations may be applied either because of faulty recognition (i.e. in the analysis) or because of faulty generation (i.e. in the resynthesis).

Certain of the error classes seem to fit quite well into this framework.

(i) *Syntactic Effects*

(a) *Without previous error.* These errors can be regarded as resulting from a transformation previously applied being applied again. Such perseveration of an operation is analogous to the errors of repetition, where an individual word or part of a word was carried on. These transformations are concerned with person, gender, number and tense.

(b) *With previous error.* These errors can be regarded as resulting from an incorrect transformation operating upon a whole phrase.

(ii) *Suffix Alteration*

As has been noted, these errors involved maintaining the root of the word and changing the original word to another part of speech or another inflection of the same part of speech by changing the final letter or letters. This could be regarded as an incorrect transformation of a single word. Such an explanation seems more satisfactory than attributing the error to inadequate perception, since it has been shown that the

end letters are more likely to be perceived correctly than the middle ones with a tachistoscopic presentation (Morton, 1964b). In addition it has been found that words on which an error is made in reading are fixated directly as often as other words (e.g. Fairbanks, 1937).

(iii) *Functional Equivalence*

These errors of substitution may be divided into two groups. The interchanging of relative pronouns, conjunctions and articles could be attributed to the fact that such words are not specified in the kernel strings but merely indicated by function. In the resynthesis then, they would be liable to be changed. The substitution of synonyms and antonyms may be regarded as an extention of the errors of suffix alteration. In the latter case the error arises from an analysis to the ' kernel word ' ; in the present case we may regard the analysis as proceeding to a ' higher ' level. Thus *evening* is analysed down to ' time of day ' (i.e. the neural equivalent of such a concept), and in the resynthesis this is changed to *morning*. This kind of explanation fits into the model in other ways. For example, in a free-association experiment (a generation situation), we find a high proportion of synonyms and antonyms given as responses, so we would expect them to be closely connected neurally.

(iv) *Omissions*

In the text passage especially, a number of articles, prepositions, conjunctions and relative pronouns were omitted. Such errors could be related to the first group of errors in the immediately preceding class, only instead of applying the incorrect transformation rule, the rule was omitted, and so the word was omitted. This suggests one practical modification to Chomsky's theories, in that some rules which strictly speaking are obligatory, are in practice treated as optional. We do not always speak with immaculate syntax ; indeed, at the present time the author is aware that he does not even write with immaculate syntax.

(v) *Insertions*

A large majority of the errors of insertion could be described as the inclusion of some optional rule.

Recapitulation

It has been seen that the vast majority of errors occurring in both experiments can be attributed to one or more of four causes.

(a) The effect of previous stimuli or responses.
(b) Errors in the immediate memory store (i.e. the material in the span).

(c) Errors attributable to the malfunctioning of syntactic mechanisms.
(d) Errors in the units corresponding to the words, arising from the inadequate use of visual cues (or from the use of inadequate visual cues in the case of the threshold experiment).

The presence of such inclusive error categories has led, together with the other results, to the formulation of a conceptual model for language generation and recognition. Clearly more experiments of such design are needed to enable the errors to be studied in more detail.

Some comments on the model

The model of verbal behaviour which has been derived is clearly too simple. We have not, for example, considered the problem of fragmentation—the recognition or speaking of parts of words. The units were related to whole words only, and yet partial responses occurred in the threshold experiment, and certain of the errors in the present experiment involved the intrusion of parts of words. However, the extension of the model to account for such errors would not alter the basic principles.

In addition, the simplicity of the model has already led to one anomaly, for if a word is to be analysed down to its neural basis or ' kernel ' (to retain Chomsky's term), then it must first be ' recognized '. This by previous statements involves the firing of a unit, which should make the word available as a response. If this is so then the word could not be erroneously transformed in the resynthesis.

Clearly then we have to state that, in a continuous task, the outputs from the units are fed into the analysing system to be transformed to the kernel equivalents before being resynthesised. Only then are the words available as responses. We have now substituted a more complex mechanism in order to fit the two models together. In justification of this procedure two major advantages may be pointed out.

(a) The syntactic information resulting from the analysis would ease the recall of the material in the span. Epstein (1961, 1962) has shown that syntactically structured nonsense such as " The yigs wur vumly rixing hum in jegest miv " was learned more readily than the same nonsense words in a random order, and in one experiment (1961), the structured nonsense was learned as well as real words in a random order.

(b) The coding of a sentence or phrase into its kernel and the transformations would seem to be more efficient than the mere storage of a list of words. The potential increase in redundancy where this is permitted would allow the recognition of inadequately perceived words and reduce the number of errors in reproduction. It might be noted that where such coding is not encouraged, e.g. by presenting successive words at 2 sec. intervals in a rote learning task, there is no difference between the speed of learning a structured but meaningless sequence or an unstructured sequence, either with real or nonsense words (Epstein, 1962).

THE SIGNIFICANCE OF ' TRANSITIONAL PROBABILITY '—AN INTRODUCTION TO THE NOTION OF A ' THOUGHT UNIT '

Another point which has been left unresolved is the nature of the action of a sentence context, via the sequential processes, in differentially lowering the thresholds of various units thus permitting recognition of some words at an exposure time which would be inadequate for the recognition of the same words in the absence of a context. We have rejected the notion of transitional probability as having any further practical use in this kind of model, since we could not have had sufficient experience of all sentences to enable us to build up the necessary statistical data. However, there is a simple way of regarding the situation which obviates such difficulties ; this involves our considering the *thought units* (for want of a better term) involved, rather than the actual words. This is best illustrated by means of an example. Take the context :

They went to see the new ——.

The proportion of times with which any word is given as a response to this sentence is termed the *transitional probability*. The implied notion that these probabilities are representative of the relative number of times the response words have been experienced (or emitted) following *precisely those context words in the given order* is rejected. Practically this is not feasible (since the principle must be extensible to *all possible* context sentences). What *is* practicable, is that the transitional probabilities are representative of the number of times the response words have been emitted or experienced following contexts of the above form and of such forms as :

We went to see the new ——.
They did not go to see the new ——.
Did they go to see the new —— ?
Have you been to see the new —— ?

and so on. Thus we can talk meaningfully about the number of times the different words have been experienced in a certain framework. It might be noted that all the above sentences might be generated from the same kernel string by application of different transformation rules.

Subjectively it seems reasonable to extend the range of relevant contexts to such sentences as :

Is it possible to see the new —— ?
You must see the new ——.
They came to see the new ——.
I would travel miles to see the new ——.

or even :

They examined the new ——.
The new —— was on view.
Come to the exhibition of new —— !

These sentences all have the same basic ' idea ' which can be expressed by two or three thought units[4] such as ' regarding ' and ' newness ',[5] with the additional ' travelling ' included in the original sentence. Experience of the sentences related to such a framework would be accompanied by experience of words which could be represented by another thought unit or units. When any one of the sentences is presented as a context, we may consider that the appropriate thought units are utilised to elicit further thought units to complete the sequence, and the choice of the word finally given as a response will depend upon the probability of the word *given the elicited thought unit.* We have returned to the term ' probability ', but it is now a practical term ; that is, it can have meaning in terms of our experience of language, and so might have meaning in neurological terms. The same cannot be said for the term ' transitional probability ' as we have previously used it.

It might be noted that Penfield (1959) has been led to talk about ' Conceptual Memory ', a ' conceptual record ' and ' the ganglionic equivalent of a concept ' (pp. 229 *et seq.*) in discussing the implications of some of his findings. In ' concept ', he includes the notion which we have termed ' thought unit '.

THE PLACE OF ' THOUGHT UNIT ' IN VERBAL BEHAVIOUR

It now seems possible to regard the selection of thought units as the first stage in generating speech. These thought units are placed in kernel strings, and the application of the appropriate transformation rules proceeds before any word is spoken. It should be noted that this is not the same as Skinner's (1957) suggestion that in the composition of a sentence, a set of ' key responses ' (nouns, verbs, adjectives) is first selected, and that the sentence is constructed on the basis of these words by the operation of a series of ' autoclitic responses ' (pp. 346 *et seq.*). Chomsky has criticised this suggestion on the basis of such results as those of Goldman-Eisler (1958) :

> " One might just as well argue that exactly the opposite is true. The study of hesitation pauses has shown that these tend to occur before the large categories—noun, verb, adjective ; this finding is usually described by the statement that the pauses occur where there is maximum uncertainty of information. Insofar as hesitation indicates on-going composition (if it does at all), it would appear that the ' key responses ' are chosen only after the ' grammatical frame '." Chomsky (1959, fn. 45, p. 54).

[4] *The idea cannot be expressed precisely in words—we need a special meta-language for such a task.*

[5] NOTE : *we have retained the word ' new ' in all the sentences, but there is no reason why we should not construct sentences including words related to ' new ' in any of the four senses listed by Roget—' different ', ' additional ', ' novel ' and ' unaccustomed '—which would be related to the original sentence.*

The present model has no difficulty in explaining Goldman-Eisler's results, since it is not necessary to specify that a word is selected to represent a thought unit before the transformation rules are selected, and the grammatical framework generated. It is possible that the words following hesitation pauses had a low probability *given the appropriate thought unit,* whereas other words, with the same *transitional probability,* which were not preceded by a hesitation pause, could have been probable words, once given the thought unit. Such a hypothesis could easily be tested, and would be valid whether the composition was ' on-going ' or not.

The suggestion that the reverse process takes place in a recognition situation was considered above when it was suggested that the ' meaning ' of a sentence might be contained in the kernel string. The extension of this idea to include the thought units would now follow naturally.

A SEMANTIC SYSTEM

If the above analysis is acceptable, we can conceive of understanding as to do with the appreciation of the relationships between thought units, and of semantic information as concerned in some way with the probability of such relationships, in the same way that a measure of statistical information in language is concerned with the probability relationships between letters or words.

We will limit the extent of further discussion to pointing to two possible extensions.

(1) We may read a passage for understanding rather than to memorise facts. The passage may consist of a series of items, already well known but arranged in such a way that some new, that is, previously unrealised, relationship is arrived at. The comprehension of the successive steps may involve the simultaneous storage of several items in order that the consequences of their juxtaposition may be seen. In crude neurological terms, we may consider that each item activates certain parts of the nervous network, and that the act of realizing a new idea involves new connections being made between the parts activated by the separate items, and that connections can only be made by parts of the network which are concurrently activated (cf. Hebb, 1949). If we are reading too slowly it is possible that the place or significance of the first or more of the relevant items will have been forgotten. If on the other hand such a passage is read at too high a speed, then the items themselves will be inadequately registered, and the connections between them, and so the sense of the passage will be lost.

If the items concerned are regarded as thought units, in the previous sense, then it need not be necessary to process fully all the words in the text, since they are not all essential for the appreciation of the thought units. (We may refer again to the fact that many structural words were omitted in the reading of the text.) From this line of thought it might be possible to explain the range of correlations reported between speed and comprehension, of -0.4 to $+0.9$ (inasmuch as these correlations are valid, see Poulton, 1958). Thus when subjects are reading a passage to remember facts, the

correlation between speed and comprehension could be negative, as in Poulton's (1959) experiment. If, on the other hand, there is a passage containing previously known ideas put together in an unusual way, the slow reader may lose the connection between them and so have a low score on a comprehension test requiring the reproduction of such connections. In this case there could be a positive correlation between speed and comprehension. In any case such considerations may help us to understand how speed of reading may be increased without any loss of comprehension and without special training (Morton 1959, 1961).

(2) Certain authors claim that separable syndromes can be identified in aphasics, concerned with ' syntactic ' and ' semantic ' disorders (e.g. Head, 1926 ; Jakobson and Halle, 1956). Thus Jakobson and Halle suggest that there are two independent processes operating in normal speech, the first represented by the use of words to symbolise concepts (semantic), and the second by use of the structural forms of connected speech (syntactic). While noting that these claims are not accepted wholly by other workers in the field (e.g. Schuell and Jenkins, 1959), it might be profitable to compare the clinical evidence in the light of the syntactic and semantic systems outlined above.

Conclusions

We may restate the final position as follows :
(a) A link has been shown between errors made in oral reading and Chomsky's (1957) model for grammar.
(b) It is suggested that in recognizing continuous prose the material is analysed down to its kernel sequences and their transformations and is then resynthesised.
(c) ' Thought units ' have been postulated to make the measure of transitional probability realistic and to link the syntactic and semantic systems.

It should be noted that the analysis and resynthesis of the material is supposed to take place whether or not the reader is aiming at understanding the passage. ' Meaningfulness ' can be regarded as resulting from some further, perhaps optional processes which operate on the thought units.

Miller (1962) has recently summarised some current American work which indicates : (a) that verbal learning is facilitated when syntactic organisation is apparent in the material ; and (b) that in recall of a sentence, the kernel string and the transformations are learned or forgotten independently. Such experiments, some based directly on Chomsky's model, strengthen the notion that a grammar can be a neural model.

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APPENDIX

Zero Order

1 enchase harlotry slight sphagnous salutary overmuch posterity chin unparalleled
2 pomade speed bartizan flare falcon paraclete papulose depth insomnia assizer
3 steps spell alms guidance postillion presently endorsee pose candelabras benedick
4 salicin titular miserere colporteur sullenness pterodactyl thunderer tic Ionic
5 ration procrastination dentine adventuress herring wether vernacular spelling
6 sooth behaviour polled canvas whitish escapement obedience hermaphrodite wield
7 excellency poignantly Samaritan back-cloth reparative thumping numeral displant
8 contributory landing current ark convener pitchfork brothel foretell lobe needlework