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ABSTRACT

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Bolt Beranek and Newman Inc.

A Chronometric Study of Component Skills in Reading

John R. Frederiksen

Technical Report No. 2

January 1978

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SUMMARY

A component skills model of reading is presented. On the basis of the model, five component factors are hypothesized: (I) Grapheme Encoding, (II) Encoding Multi-letter Units, (III) Phonemic Translation, (IV) Automaticity of Articulation, and (V) Depth of Processing in Word Recognition. The fit of the hypothesized component factor model is tested using covariance data for eleven chronometric measures, chosen to reflect separate stages of processing. The fit of the structural model is found to be good (p=.2). Three alternative models are developed, each representing a simplification of the general model; in each case the alternative structural model is rejected. The component skills model accounts for nearly all of the variance in subjects' general reading ability, as measured by standard tests of reading comprehension.

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A CHRONOMETRIC STUDY OF COMPONENT SKILLS IN READING

I. INTRODUCTION

Psychometricians have long sought to develop skill measures covering the repertoire of human cognitive abilities (cf. Thurstone, 1938; Thurstone & Thurstone, 1941; French, 1951; French, Ekstrom, and Price, 1963; Guilford, 1967; Carroll, 1974). The goal has been to build tests of information-handling skills that represent particular methods for processing information, but that at the same time have applicability across a variety of task environments. While this early work on cognitive and perceptual abilities is in many ways compatible with modern cognitive psychology in its effort to distinguish component processes in human skilled performance, the historical emphasis upon cross-situational information-processing abilities has limited the utility of such measures in the analysis of the particular component skills that are acquired in becoming proficient within a single task domain such as that of reading.

In an effort to develop measures that are diagnostic of the sources of reading disability among naval recruits, we have been engaged in a series of studies of individual differences in the component skills involved in reading. The general goal of this work has been to develop a set of component skill measures that represent the particular information-handling processes used in reading, as they are conceptualized in current theories of the reading process. These include skills involved in the translation of orthographic patterns into "sound" patterns and the accessing of lexical information, as well as perceptual skills of pattern recognition and encoding. A second goal has been to explore the potential offered by a chronometric approach to the measurement of component skills in reading. There are a number of reasons why the measurement of processing times may provide an important tool for the assessment of skills in young adults. First, it is difficult to generate errors in such basic skills as letter identification, phonic analysis, and the like in mature subjects. Yet, individual differences in skill may still be apparent in their processing efficiencies. Second, studies of reaction times in human information processing have served experimental psychologists well in their efforts to build precise models for reading. In particular, the subtractive method for analysing reaction times (RTs) has proven its value as a technique for deriving measurements that reflect a single locus of information processing. In the subtractive method, the difference in RTs is calculated for experimental conditions that vary in the processing load they place on some single processing subsystem. RT differences (or contrasts) then provide a measure of the relative difficulty in processing under the contrasted conditions. With a careful choice of contrasts among experimental conditions, it has been our hope that measurements of component processing skills can be derived.

Approaches to Validation

The assertion that a particular RT contrast represents a designated component skill must in the first case be backed up by experiments designed to establish the construct validity of the particular constrasts. Thus, the first source of information concerning the validity of component skill measures comes from an analysis of the individual experimental tasks from which the RT contrasts are derived. In this analysis, variations in experimental conditions must be shown to yield the expected changes in response times as required by theory.

The second source of information leading to construct validation results from a comparison of measures derived from different experimental contexts. From a set of experimental tasks, several measures are derived for each hypothesized component process, each one based upon a separate constast among RTs for a different set of experimental conditions. A theoretical prediction can then be made about the relationships among these skill measures: alternative measures of a designated component skill are hypothesized to form a common factor that is distinct from the factors formed by other component skills. Note that it is the high degree of specificity about the component skills measured by the chosen RT contrasts that allows us to generate and test a specific hypothesis about the factor structure underlying our set of component skill measurements. And, verification of this hypothesis will permit us to conclude with confidence that the component skills derived form our model of reading do in fact represent the postulated sources of individual differences among readers.

Finally, the role of component skills in establishing an individual's general level of reading ability can be investigated by using the component skill factors to predict other, more general measures of reading performance. This provides us with a third source of validating information: the evidence that particular component skills contribute to skilled reading as measured by conventional tests of reading ability and comprehension.

II. COMPONENT SKILL MEASURES

Theoretical Model

The theoretical model guiding the selection of component skill measures is illustrated in Figure 1. The model disinguishes four main processing levels: I. Visual Feature Extraction, II. Perceptual Encoding, III. Decoding, and IV. Lexical Access. Perceptual Encoding is further subdivided into a component representing the encoding of individual graphemes and a component representing the encoding of visually familiar, multi-grapheme units (e.g., SH, ING). Finally,

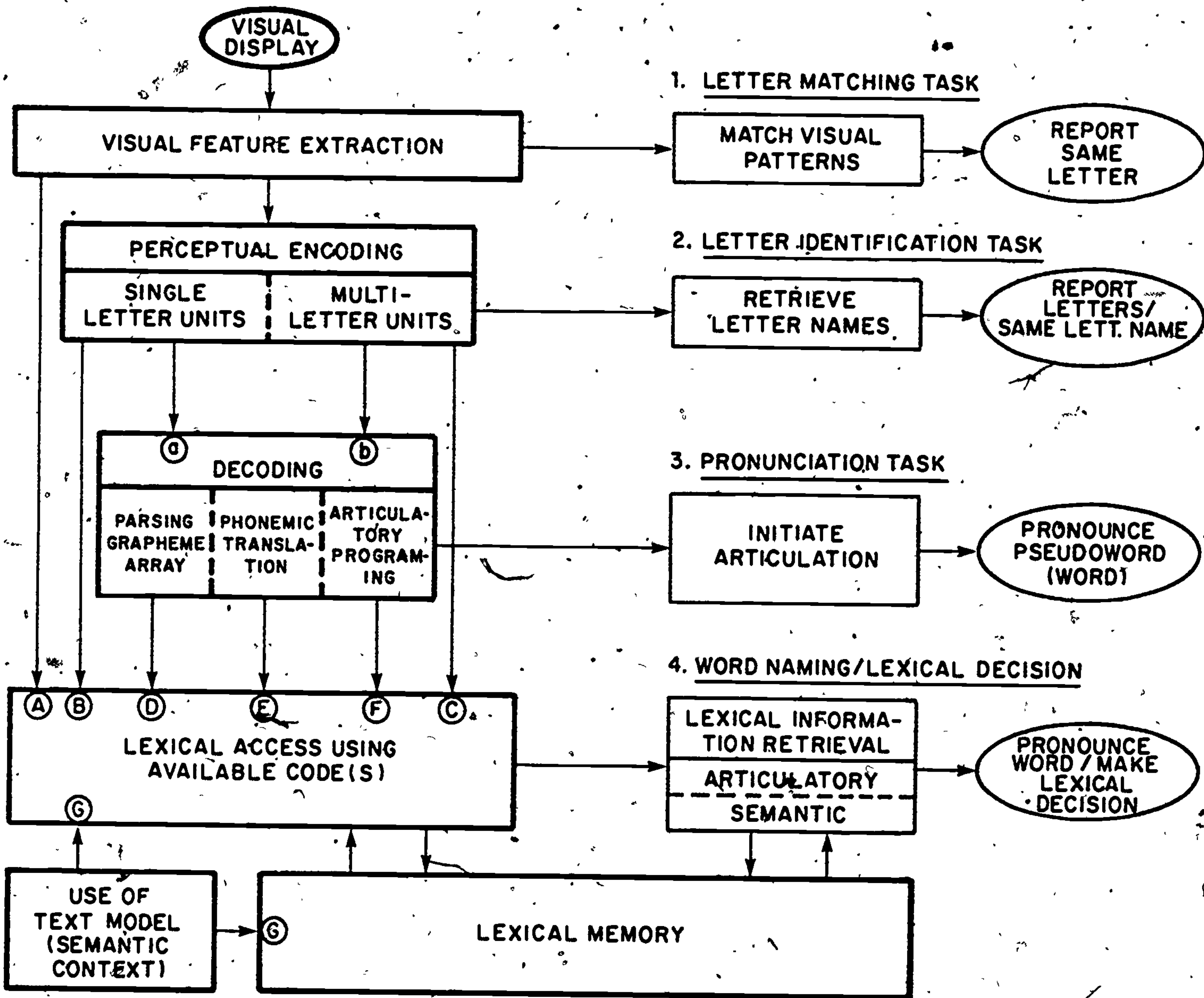

Fig. 1. A schematic rendering of the processing model representing component skills in reading. Four processing levels are distinguished: Visual Feature Extraction, Perceptual Encoding, Decoding, and Lexical Access. While these processes are hierarchically arranged, initiation of higher-level operations does not await completion of prior operations in the hierarchy. Decoding can thus be initiated on the basis of (a) independently-encoded graphemes, or (b) multi-grapheme units. Lexical access can be based upon any of the following input codes: (A) visual features, (B) independently encoded graphemes, (C) multi-grapheme units, (D) a parsed grapheme array, (E) a phonological/phonemic translation, (F) a speech contour, or (G) semantic/syntactic constraints on word identity. Experimental tasks 1-4 are thought to require different characteristic depths of processing.

Decoding is divided into processes of parsing (Spoehr & Smith, 1973), phonemic translation, and articulatory programming.

A general feature of the model is the notion that, while these processes are hierarchically arranged, the initiation of higher-level operations does not necessarily await completion of prior operations in the hierarchy. Thus, Lexical Access can be initiated on the basis of any of the following input representations: (a) a spatial distribution of visual features, (b) an array of independently encoded graphemes (e.g., T R A I N I N G), (c) encoded, overlapping multi-letter perceptual units, as in ((TR)((AI)N))(I(NG)) (see also Figure 2), (d) a parsed grapheme array (having a form that may be similar to that illustrated in Figure 2), (e) a phonemic translation of the orthographic pattern, as in t r e n ɪ ŋ, or (f) a speech contour, having assigned stress and intonation. Input representations a-f represent differing depths or degrees of processing prior to lexical access.[1] In a similar fashion, Decoding can take place on the basis of (a) a set of independently encoded graphemes, or (b) encoded, multi-letter perceptual units. Note that, according to the model, the demands placed upon the decoding component are

[1]To handle reader' use of context in lexical retrieval, an additional input code (g) represents semantic/syntactic constraints based upon a contextually-derived model of discourse. However, skills involved in the use of context are not included in the present set of experimental measures and will not be considered here.

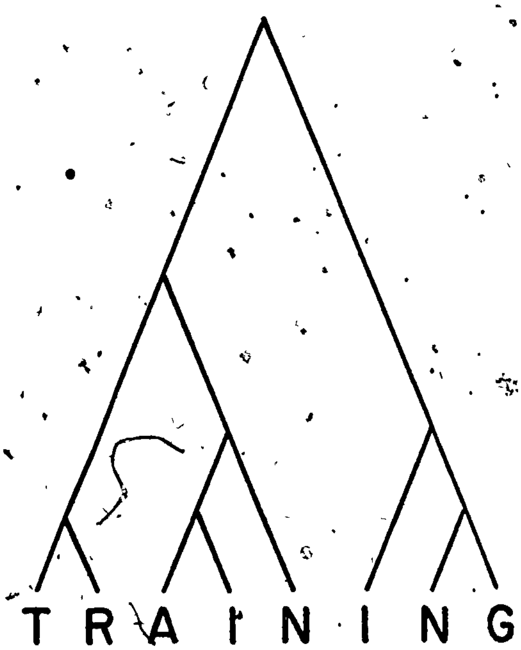

Figure 2. An illustration of the structural organization that is implicit in the perceptual encoding of the multi-letter units (TR), (AI), (N), (I), (NG), (AIN), (ING), and (TRAIN).

greatly lessened when the grapheme representation is made up of multi-letter units having functional utility for decoding, such as affixes, double-vowels, consonant clusters, and the like, as illustrated in Table 1.

Experimental Tasks

Component skill measures that are referenced to particular stages of processing have been derived from four experimental tasks:

1. Letter Matching. In the letter matching task, the subject is shown a brief (50 msec) display containing a pair of letters that (a) have the same name and form (AA, aa), (b) have similar names but differ in form (Aa), or (c) are totally different letters (Ad, ad, AD). The subject's task is to indicate whether the letter names are the same or different by pressing an appropriate response key. Two RT contrasts are derived from this task: Speed in Letter Encoding (Variable 1 in Table 2) is measured by subtracting the mean RT for physically similar letters (AA, aa) from the mean RT for letters differing only in case (Aa, Dd) (Posner & Mitchell, 1967). Facilitation in Encoding Jointly Occuring Letters (Variable 3) is measured by subtracting the RT for letters differing only in case (Aa, Dd) from the RT for letters that are completely different (Ad, aD). This RT comparison measures what Posner in his later work has

TABLE 1

Decoding under Two Levels of Perceptual Encoding

Process	Perceptual Encoding: Single-Letter Units	Perceptual Encoding: Multi-Letter Units
Stimulus	SHOOTING	SHOOTING
Encoded Visual Units	S/H/O/O/T/I/N/G	SH/OO/T/ING
Decoding: Parsing Grapheme Array	SH/OO/T/ING	
Decoding: Phonemic Translation	ʃutɪŋ	ʃutɪŋ
Assignment of Stress and Intonation	ʃut'ɪŋ	ʃut'ɪŋ

TABLE 2

Variables Used in the Component Skills Analysis of Covariance Structures*

VARIABLE	CODE	TASK	Results of ANOVA+
1. Speed in Letter Encoding: RT for dissimilar cases (Aa) minus RT for similar cases (AA, aa)	Letter Encoding	Letter Matching	p<.05
2. Scanning Speed: Increment in RT per letter position.	Scanning Speed	Bigram Identification	p<.05
3. Facilitation in encoding jointly occuring letters: RT for dissimilar letters (Ad) minus RT for similar letters (Aa).	Percept. Facilitation	Letter Matching	-
4. Bigram Probability Contrast: RT(Low Prob. Bigram) minus RT(High & Middle Prob. Bigrams)	Bigram Probability	Bigram Identification	p<.05
5. Array-Length Contrast: Increase in RT for each added letter.	Length: Pseud.	Pseudoword Decoding	p<.06
6. Syllable Contrast: RT for 2-Syllable minus RT for 1-Syll.	Syllable: Pseud.	Pseudoword Decoding	-
7. Vowel Complexity Contrast: RT for -vv- minus RT for -v-.	Vowel: Pseud.	Pseudoword Decoding	-
8. Syllable Contrast (as above, but for vocalization durations.)	Syllable: Pseud. (Dur.)	Pseudoword Decoding	p<.01
9. Vowel Complexity Contrast: (as above, but for vocalization durations).	Vowel: Pseud. (Dur.)	Pseudoword Decoding	p<.10
10. Percent Drop in Decoding Indicators for HFW and Pseudo.: (Sum 5-9 for Pseud. - Sum 5-9 for HFW)/(Sum 5-9 for Pseudowords).	Δ% Decoding Pseud.-HFW	Word Naming	-
11. Percent Drop in Decoding Indicators for HFW and LFW: (Sum 5-9 for LFW - Sum 5-9 for HFW)/ (Sum 5-9 for LFW).	Δ% Decoding LFW-HFW	Word Naming	-

*All comparisons are for mean response times unless otherwise noted.
+Values of the variable differ for subjects at four reading levels at the indicated significance level.

termed category facilitation (Posner & Snyder, in press). These two measures are thought to refer respectively to the two subdivisions of Perceptual Encoding -- encoding of individual graphemes, and encoding of multi-grapheme units.

2. Bigram Identification. In this task, the subject is shown a 4-letter array, preceeded and followed by a 300 msec pattern mask (e.g., ####, followed by SHOT, and that followed by ####). The actual stimulus array varies from trial to trial: On a third of the trials, the stimulus items are familiar English words, while on the remaining trials the items are presented with two letters masked so that only a single pair of adjacent letters (a bigram) is visible (e.g., SH##, #AB#, ##TH). Further, the bigrams are chosen so as to differ in location within the item (positions 1-2, 2-3, or 3-4), frequency of occurence in English (e.g., TH [high], GA [middle], and LK [low]), and likelihood of occuring in their presented position within a four-letter word (e.g., TH## [high] versus #TH# [low]) (cf. Mayzner & Tresselt, 1965). In all cases, the subject's task is to report the letters that he can see, as quickly and accurately as possible. The response measure is the RT measured from the onset of the stimulus item to the onset of the subject's vocal report of the letters (Frederiksen, 1978). Two measures are derived from this experiment. Scanning Speed (Variable 2) is measured by subtracting the mean RT for bigrams presented in positions 3-4

from the mean for bigrams presented in positions 1-2 and then dividing by 2. This gives the increment in RT for each shift to the right in letter position. The Bigram Probability Contrast (Variable 4) is measured by subtracting the RT for high and middle probability bigrams from that for low probability bigrams. This variable gives the penalty in processing time brought by reducing the linguistic frequency of a bigram unit by the given amount. Variable 4 provides a second measure of the ability to encode orthographically regular multi-grapheme units. Variable 2 (scanning speed) is thought to provide a more general measure of Perceptual Encoding, and to reflect both the single grapheme and multi-grapheme subprocesses.

3. Pseudoword Decoding. In the pseudoword decoding task, subjects are asked to pronounce pseudoword items that have been derived from actual English words by changing a single vowel (e.g., BRENCH, derived from BRANCH). The set of pseudowords covers a number of orthographic forms, including variations in length, number of syllables, and type of vowel (Frederiksen, Note 1). We measure the RT from the presentation of the display to the onset of the subject's vocalization and the duration of his vocal response. Five measures of decoding are derived from this experiment: The Array Length Contrast (Variable 5) is the increase in mean RT for each added letter (e.g., CCVC, CCVCC, CCVCCC). The Syllable Contrast (Variable 6) is measured by

subtracting the mean onset RT for two-syllable items from that for one-syllable items that are matched on initial phoneme and orthographic form (e.g., CVC-CV and CVCCV). The Vowel Complexity Contrast (Variable 7) is measured by subtracting the mean onset RT for pseudowords having sequences of two vowels (e.g., CVVCC) from that for pseudowords having single vowels (e.g., CVCCC). In addition, the syllable and vowel complexity contrasts were caluclated using vocalization durations, forming Variables 8 and 9. These contrasts in all cases reflect the increase in processing difficulty occasioned by increasing the orthographic complexity of a stimulus item in a designated manner, and are regarded as measures of Decoding. It is thought that measures based upon RT to onset of vocalization tap earlier decoding processes of parsing and phonemic translation, while measures based upon vocalization durations tap later processes of articulatory programming, stress assignment, and the establishment of prosodic features.

4. Word Naming. This task is in every respect similar to the Pseudoword Decoding task, except for the use of English words in place of pseudowords. In addition to variations in orthographic form, the stimulus words are chosen to represent two linguistic frequencies of occurrence, low-frequency words (having

a mean SFI index[2] of 27.0) and high frequency words (having a mean SFI index of 56.4). Each of the five contrasts described above for the Pseudoword Decoding task is also calculated for the Word Naming task, for both high frequency words (HFWs) and low frequency words (LFWs). Two measures were constructed in order to compare the extent of use of Decoding in processing high and low frequency words and pseudowords. The Percent Drop in Decoding Indicators for HFWs and Pseudowords (Variable 10) is measured by summing the values of the five contrasts for both HFWs and Pseudowords, and calculating the percent drop using the formula:

% Drop = (Sum(Pseudowords) - Sum(HFWs)) / Sum(Pseudowords).

The Percent Drop in Decoding Indicators for HFWs and LFWs is measured in a similar manner, by substituting LFWs for pseudowords in the above comparison. These variables were developed to measure a fundamental characteristic of Lexical Access: the depth of processing of orthographic information that characteristically takes place prior to lexical retrieval. Large values for either of these contrasts indicate a decrease in depth of processing when the stimuli are familiar English words, while small values incidate that there is a continued use of word-analysis skills in the recognition of common words.

[2] The SFI or Standard Frequency Index is a logarithmically transformed word frequency scale (Carroll, Davies, & Richman, 1971). High values represent English words that occur commonly in text; low values represent uncommon words.

Relation to Hypothesized Component Skills

It has been our belief that the set of measures we have described will permit us to distinguish the five component processes alluded to above and listed in Table 3. The first two components (or factors) refer to the two subprocesses of Perceptual Encoding, dealing with the encoding of individual graphemes and with multi-grapheme units. The third and fourth components refer to hierarchically organized levels of Decoding: Phonemic translation includes the parsing of a grapheme array and the application of orthographic rules to derive a phonemic representation. Automaticity of articulation refers to operations performed on an initial phonemic representation in deriving an articulatory or speech representation, including the assignment of stress pattern and other prosodic features. The last component process refers to what is probably the most fundamental characteristic of Lexical Access, namely, the depth of processing of the orthographic code prior to lexical retrieval.

The relations we have described between component skill measures and component processes can be summarized compactly in a factor matrix, shown in Table 4. Ignoring for the moment the numerical values contained in the table, the hypothesized factor structure is represented by the positions of zeroes and positive values in the table. A value (or loading) of zero for a variable

TABLE 3

Definition of Component Processes
Hypothesized in the Analysis of Covariance Structures

FACTOR	NAME	DESCRIPTION
I.	Grapheme Encoding	Efficiency in Letter Identification
II.	Perceptual Facilitation in Encoding Multi-letter Arrays	Efficiency in Encoding Orthographically Regular or Redundant Letter Sequences.
III.	Phonemic Translation	Efficiency in Applying Spelling Rules to Derive a Phonological/Phonemic Representation
IV.	Automaticity of Articulation	Efficiency in Articulation; Syllabication, Assignment of Stress, Prosodics.
V.	Depth of Processing in Word Recognition	Use of Visual or Whole-Word Recognition Strategy in Recognizing Common Words.

TABLE 4

Maximum Likelihood Estimates of Factor Loadings and Uniquenesses for the Experimental Variables*

VARIABLE	FACTOR I	II	III	IV	V	Uniqueness
1. Letter Encoding	1.00	0.	0.	0.	0.	.00
2. Scanning Speed	.64	.53	0.	0.	0.	.53
3. Percep. Facilitation	0.	.62	0.	0.	0.	.62
4. Bigram Probability	0.	.54	0.	0.	0.	.71
5. Length: Pseud.	.16	0.	.77	0.	0.	.36
6. Syll.: Pseud.	0.	0.	.80	0.	0.	.37
7. Vowel: Pseud.	0.	0.	.55	0.	0.	.70
8. Syll.: Pseud. (Dur.)	0.	0.	0.	.96	0.	.08
9. Vowel: Pseud. (Dur.)	0.	0.	0.	.36	0.	.87
10. Δ% Decod.:Pseu.-HFW	0.	0.	0.	0.	.24	.94
11 Δ% Decod.:LFW-HFW	0.	0.	0.	0.	1.00	.00

*Zero loadings were fixed by hypothesis; the goodness of fit of the hypothesized structure is measured by $\chi^2(32) = 38.4$, $p = .20$.

indicates that that variable is by hypothesis not considered a measure of the particular component process, and is not expected to be related to that component except through possible correlations between component processes. A positive loading indicates that the variable in question is hypothesized to be a measure of the particular component process, although the exact value of the loading remains to be estimated on the basis of data. By reading down a column of Table 4, one can see which RT contrasts have been hypothesized to be markers of a given factor. By reading across rows, one can see the hypothesized factorial composition for each variable.

III. EVALUATION OF THE COMPONENT SKILLS MODEL

Method

So far, this discussion has focused on the nature of component processes in reading and the types of chronometric measures used in their measurement. Our ability to validate the component skills analysis is based upon an important development in the application of statistical theory to the problem of factor analysis, worked out a few years ago by Karl Jöreskog (1970). Jöreskog's technique allows us to estimate directly the parameters of a factor model using the method of maximum likelihood, provided that the number of parameters to be estimated does not exceed the degrees of freedom in the covariance or correlation matrix being factored and that the hypothesized factor matrix is unique in that it precludes rotation of axes. The investigator reduces the number of parameters in the analysis by constraining the parameters of the model (values in the factor matrix, intercorrelations among the factors, or uniquenesses) to have specified values or to be equal to other parameters in the set to be estimated. Jöreskog's (Note 2) program provides a test of the fit of the hypothesized factor structure, represented by the choice of constraints on the values of the parameters. Finally, comparisons among alternative structural models can be made using a likelihood ratio test.

Subjects

Data available for testing the structural model in Table 4 are the scores of 20 subjects who were tested on each of the tasks we have described. The subjects were high school sophomores, juniors, and seniors, and represented a wide range of reading ability levels. Their reading scores on the Nelson-Denny Reading Test ranged from the 16th to the 99th percentile. Approximately equal numbers of subjects were drawn from a city and a suburban high school.

Results

The goodness of fit of the hypothesized factor structure is given in Table 4, along with estimated values for the factor loadings. The obtained Chi-square of 38.4 (with 32 degrees of freedom) has a probability of .2, indicating that the sample correlation matrix would be obtained with high likelihood given that the hypothesized structure is the true factor structure. Moreover, the values of the loadings in the factor matrix support in detail the hypothesized component processes model. Factor I, Grapheme Encoding, is clearly marked by the letter encoding and scanning speed measures. Factor II, Encoding Multi-Letter Units, is marked by the perceptual facilitation contrast derived from the letter matching task and the bigram probability contrast derived from the bigram identification task. The three decoding indicators calculated from onset RTs in the pseudoword pronuncition task load on the Phonemic Translation factor (III), and the two decoding contrasts based upon vocalization durations load on the Articulation factor (IV). Finally, the measures of processing depth in reading words both load on the last factor (V), Depth of Processing in Word Recognition.

Estimates of the intercorrelations among the factors are presented in Table 5. A likelihood ratio test of the hypothesis that the factors are mutually orthogonal yielded X^2 (10)=20.29, with $p<.05$. The factors can therefore be assumed to be correlated with one another. Several patterns among these correlations are of interest. (1) Factors III-V appear to be mutually orthogonal, suggesting that each is tapping an

TABLE 5

Maximum Likelihood Estimates of Intercorrelations Among the Factors*

	FACTOR	I	II	III	IV	V
I.	Grapheme Encoding	1.00				
II.	Percep. Facilitation	-.32	1.00			
III.	Phonemic Translation	.09	.41	1.00		
IV.	Automaticity of Articulation	.58	.24	-.17	1.00	
V.	Depth of Processing in Word Recognition	-.11	.52	.08	.01	1.00

*A likelihood ratio test of the hypothesis of orthogonality of the factors yielded $\chi^2(10) = 20.29$, with $p < .05$.

independent aspect of the reading process. Facility in parsing/phonemic translation appears to be uncorrelated with processes related to articulation, and the extent of decoding in reading common words is not related to a subject's level of skill at the decoding level. (2) The two aspects of Perceptual Encoding, on the contrary, do appear to be related to skill in decoding and lexical access. Subjects who are highly efficient in encoding multi-letter graphemic units are faster in phonemic translation (r=.41) and in articulation (r=.24), and tend to use their decoding skills in accessing common English words in their lexicon (r=.52). It is subjects who are less proficient in identifying multi-letter units that decrease their depth of processing when reading high frequency words. Interestingly, there appears to be a small, reciprocal relationship between efficiency in single letter encoding and in encoding multi-letter units (r=-.32). (3) Finally, it appears that subjects who are rapid in encoding individual graphemes are also more rapid in articulatory processes (r=.58).

Evaluation of Alternative Structural Models

Three alternative hypotheses about the factor structure were developed in order to see if the finer distinctions made between subprocesses of Perceptual Encoding and Decoding are necessary. The results of these investigations are presented in Table 6. In the first alternative model, we were interested in the

TABLE 6

Test of Fit for Three Alternative
Hypotheses about the Covariance Structure

Alternative Model	Effects on Hypothesized Factor Structure	Number of Factors	Chi-square	d.f.	p
1. No distinctions are made between Subclasses of Perceptual Skills	Factors I and II are combined into a single Perceptual Encoding factor.	4	54.16	37	.034
2. No Distinctions are made between Subclasses of Decoding Skills.	Factors III and IV are combined into a single Phonemic Translation factor.	4	54.00	36	.027
3. No Distinction is made between the Perceptual Encoding of Multi-letter Units and the Parsing of a Grapheme array as a Component of Decoding.	Factors II and III are combined into a single Parsing and Phonemic Translation factor.	4	51.12	36	.049

distinction between perceptual encoding of individual graphemes and multi-grapheme units, represented by factors I and II. These two factors were, accordingly, combined into a single Perceptual Encoding factor; in all other respects, the model was similar to the general model in Table 4. The test of fit yielded χ^2 (37)=54.16 with p=.034, leading us to reject the first alternative model and to conclude that a distinction must be maintained between the two aspects of Perceptual Encoding as originally hypothesized.

In the second alternative model, the distinction between early (parsing, phonemic translation) and late (articulatory programming) decoding processes was dropped. Accordingly, factors III and IV were combined into a single Decoding factor, while in all other respects the model was similar to our original model. The test of fit yielded χ^2(36)=54.0 with p=.027. We were thus again led to reject the alternative model and to conclude that the distinction between levels of analysis within the decoding process must be maintained.

In the third alternative model, we were interested in testing the importance of the distinction between the perceptual parsing of a grapheme array (represented by factor II) and parsing conceived as a component of decoding (factor III). Accordingly, in this model factors II and III were combined into a single factor. The likelihood ratio test yielded χ^2(36)=51.12

with $p=.049$, and again we were led to reject the alternative model. Evidently the perceptual grouping of graphemes into overlapping, multi-grapheme units is distinct from rule-based processes involved in the translation of an orthographically regular array.

Testing the External Validity of the Component Skills Model

A final source of information concerning the validity of the component skill measures lies in their relationship to other, more general measures of reading proficiency. We are interested here in establishing what role the component processes play in setting levels of reading skill, as measured by conventional tests of reading ability and comprehension. Two sets of criterion variables were used: (1) Chronometric Measures representing overall levels of performance in reading individually presented words and pseudowords, and (2) Reading Test Scores, including the Nelson-Denny Total Score (the sum of Vocabulary and Reading Comprehension subtests), Nelson-Denny Reading Rate, and the Gray Oral Reading Test, Total Passage Score (which includes number of pronunciation errors and reading rate). The loadings of each of these criterion variables on the component skill factors were calculated using a factor extension procedure, and are presented in Table 7.

TABLE 7

Loadings of Criterion Variables
on the Component Skill Factors

Criterion Variable	FACTOR I GRAPHEME ENCODING	II PERCEPTUAL FACILITATION	III PHONEMIC TRANSLATION	IV AUTOMATICITY OF ARTICULATION	V WORD RECOGNITION	SQUARED MULT. CORRELATION
Chronometric Measures						
1. Mean Onset Latency:Pseudo.	.14	.70	.35	.59	.29	.73
2. Mean Onset Latency:LFW	.33	.43	.01	.49	.36	.56
3. Mean Onset Latency:HFW	.27	.55	.12	.46	.35	.68
4. Word Frequency Effect (Onset RT)	.08	.72	.33	.27	.22	.99
Reading Test Measures						
5. Nelson-Denny: Total Score	-.42	-.59	-.02	-.69	-.35	1.00
6. Nelson-Denny: Speed	-.12	-.52	-.23	-.62	-.25	.73
7. Gray Oral Reading	-.39	-.24	.09	-.43	-.37	.53

Chronometric Measures. Mean onset latencies for pronouncing pseudowords and low or high frequency words (criterion variables 1-3) are highly predictable from the component skill factors, with multiple correlations[3] of .85, .75, and .82, respectively. There is a high degree of consistency in the pattern of loadings for each of these criterion variables: While Grapheme Encoding is positively --but not strongly -- related to efficiency in reading words and pseudowords, the ability to encode multi-letter units is the strongest predictor of oral reading latencies. Phonemic Translation is related to pseudoword decoding latencies, but not to latencies for pronouncing English words. However, Automaticity of Articulation does turn out to be a strong predictor of reading latencies. Finally, the loadings on the Visual Recognition factor support our earlier contention (Frederiksen, 1976) that it is the poorer readers that use a visual or whole-word basis for recognizing familiar words.

The difference in reading latencies for low and high frequency words was entered as the fourth cirterion variable. The items contributing to the high and low frequency scores were balanced in number of letters, and we find that the grapheme encoding component does not predict this criterion. On the other hand, high and low frequency words do differ in the populations

[3] The multiple correlations are subject to shrinkage and should be regarded only as indices of the degree of shared variance between the component skill factors and the criteria.

of graphemes they contain, and we are thus not surprised to find that the multi-letter encoding factor is a strong predictor of differences in latencies for reading low and high frequency words. Finally, the positive loadings on factors III-V suggest again that high and low frequency words are analysed in different ways prior to lexical retrieval.

Reading Test Measures.[4] The scores for the three reading test measures are highly predictable from the component skill factors, with multiple correlations of 1.00, .85, and .73 for the Nelson-Denny Total, Reading Rate, and Gray Oral Reading Test scores, respectively. Again, the strongest predictors appear to be Encoding Multi-Letter Units and Automaticity of Articulation. Subjects scoring highly on the reading tests also tend to be efficient in Graphme Encoding and to use thier decoding skills in recognizing familiar English words as well as less familiar items. Low scoring subjects again are found to be less efficient in encoding individual graphemes, in perceiving multi-grapheme units, and in their degree of automaticity in the final stages of decoding, and they tend to recognize familiar words on the basis of their visual characteristics.

[4] The loadings are negative, indicating that efficiency in processing within the domain of each component skill is related to high scores on the reading tests.

IV. SUMMARY AND CONCLUSIONS

The evidence we have collected supports a component process model for reading that distinguishes at least five component skills: I. Efficiency in perceptual encoding of individual graphemes, II. Efficiency in encoding orthographically regular, multi-grapheme units, III. Efficiency in parsing an encoded grapheme array and in applying letter-sound correspondence rules to derive a phonological/ phonemic representation, IV. Automaticity in deriving a speech representation, in the assignment of stress and other prosodic features, and V. the process of lexical retrieval, characterized by the depth of processing (perceptual encoding and decoding) that takes place prior to lexical access. The picture we have gained of the patterns of intercorrelation among component skills and their relatedness to measures of reading proficiency permit us to draw two more general conclusions:

1. <u>While component processes can be regarded as hierarchically ordered, the initiation of high order processes</u> (e.g., lexical retrieval) <u>does not necessarily await the completion of earlier processing operations</u>. Thus, the depth of processing prior to lexical retrieval is seen to vary with the familiarity of a word. High frequency words may be recognized on the basis of their visual characteristics, without the completion of the grapheme encoding and decoding processes required for recognizing unfamiliar words.

2. There are interactions (trade-offs) between the use of skills at one level of processing and the mode of processing and processing efficiency at higher levels of processing. Thus, an ability to perceptually encode multi-letter units reduces the demands placed on the decoding component, with a consequent increase in efficiency of decoding. Readers who have high scores on factor II (Encoding Multi-letter Units) are also the fastest decoders, and they are likely to apply their efficient word-analysis skills in recognizing common as well as rare words. On the other hand, readers who have a low level of skill in perceptually encoding multi-letter units have the greatest difficulty in decoding grapheme arrays into "sound," and they are the ones who are most likely to reduce the depth of processing when visually familiar words are encountered. This processing interaction illustrates how the mode of processing at a high level (here, the type of evidence used as a basis for performing lexical access) is influenced by the level of skill in processing at a lower level. The modification in procedures for high-level processing (lexical access) serves to compensate for low efficiencies in lower-level component processes. Thus, the system adapts to it's own deficiencies, and is able to improve it's overall performance when the stimulus materials permit such an adjustment of processing characteristics to take place. In general, we believe that models for human information processing

within a complex domain such as that of reading will have to account for individual differences in the procedures used by the system in allocating its components for the solution of a problem, as well as for skill differences among subjects in processing efficiencies within the component processes themselves.

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