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Special Issue

PSYCHOLOGICAL PROCESSES IN READING

Guest Editors: Dominic Massaro and Cesare Cornoldi

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Merald E. Wrolstad, Ph.D., Editor and Publisher
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SPECIAL ISSUE

Psychological Processes in Reading

EDITED BY

Dominic Massaro, University of California, Santa Cruz

Cesare Cornoldi, University of Padova, Italy

The papers in this special issue evolved from a subset of those given at the International Conference on Reading held in December 1982 in Padova, Italy. They have been selected to provide the reader with a broad coverage of extant reading-related research, theory, and practice. The papers make transparent that there are a variety of processing stages involved in reading and that it is fundamental to address the workings of each individual stage. Also central to reading is the nature of the representation and utilization of various forms of knowledge. Baddeley's paper gives an informative overview of his research on working memory. The research has led to the development of a comprehensive model of the structures and processes involved, and the model serves as a useful heuristic for the investigation of reading performance, comprehension, and learning to read. Massaro's article is a continuation of his study of spelling constraints and how they are used in reading by readers of varying skill and development. Simion, Benelli, and Tarantini employ a well-developed information-processing task to assess the nature of the representation and activation of letters and geometrical figures and the changes that occur with reading development. Burani, Salmaso, and Caramazza address the important question of the relative contributions of surface word forms and root morphemes in word representation and recognition. Flores d'Arcais documents large differences in the reading of function and content words and how these differences change with development. Cavedon, Cornoldi, and DeBeni explore the recognition and memory of words by hearing and deaf individuals and find evidence relevant to the reading difficulty experienced by the deaf. Masterson reveals some impressive correspondences between the reading deficits of patients with neurological damage and normal children with reading disorders. Blachowicz provides an informative overview of the recent changes in the theoretical conception of memory and language comprehension and how these are influencing reading research, assessment, and teaching. This superficially mixed salad will provide the reader with representative studies and findings in reading-related research. To this reader, I read progress. Enjoy!

We were overwhelmed with the enthusiasm for reading research and practice expressed by both Italian teachers and administrators, and are grateful for financial support for the Conference given by the Public Administration of the Provincia di Padova. A report has been published by the Cooperativa Libraria dell' Universita di Padova. Our fond memories of the generosity and warm hospitality of our hosts—the Instituto di Psicologia of the Universita di Padova—will not fade! D.M.

Reading and Working Memory

Alan Baddeley
MRC Applied Psychology Unit
Cambridge, England

The concept of working memory is outlined, with particular reference to a hypothetical subcomponent, the articulatory loop. Research on the possible involvement of the articulatory loop in fluent adult reading is discussed in connection with the effects of phonological similarity within the material to be read, and the effects of articulatory suppression. Evidence from written and spoken puns is also considered. The model is then used to investigate the comprehension and reading performance of a patient with defective STM attributable to an impairment in the phonological short-term store. The evidence combines to suggest that the articulatory loop is not essential for most fluent reading, but is important for the accurate processing of complex text. The final section considers the possible involvement of the articulatory loop in learning to read, presents evidence for its importance, and suggests possible strategies for optimizing its use.

The Concept of Working Memory

During the 1960's there was a dramatic increase in the amount of both experimental and theoretical work devoted to the topic of short-term memory. By the early 1970's the field had become enormously complicated, with a wide range of experimental techniques, all claiming to tap short-term memory, and a bewilderingly large range of models. In an attempt to clarify this increasingly complex picture, Graham Hitch and I decided to ask the simple question "What is short-term memory for?". The answer assumed by most theorists was that short-term memory (STM) acts as a temporary working memory. A wide range of cognitive tasks require the manipulation of information, and this in itself demands temporary storage; STM was assumed to provide the storage, and hence to play a central role in such important cognitive skills as reading, understanding, and reasoning. There was however virtually no direct evidence in support of this widely held view. We therefore decided to collect such evidence.

We required our subjects to perform a range of tasks including reasoning, learning, and prose comprehension while remembering sequences of digits such as might be involved in remembering a telephone number. The assumption was that the greater the number of digits held in immediate memory the more of the limited capacity of the working memory would be occupied, and the less would be left for

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Author's address: MRC Applied Psychology Unit, 15 Chaucer Road, Cambridge CB2 2EF, England.

reasoning or comprehending. Our results indicated that such memory tasks do impair performance, but that the effect is considerably less dramatic than might have been expected. Impairment in performance on a complex reasoning task, for example, occurred only when the subject was required to hold six or more digits, a load approaching the limit of his memory span (Baddeley and Hitch, 1974). As a result of this and other studies, we suggested that instead of a single unitary short-term memory system, working memory should be regarded as a set of inter-related subsystems. A given task such as digit span might load heavily on some of these, but relatively lightly on others.

We began by dividing working memory into three subsystems. The first of these we termed the central executive. It was assumed to be responsible for running the whole system, and to be limited in attentional capacity, but able to offload some of its demands onto a series of subsidiary slave systems. Two of these have been explored in detail, namely *the articulatory loop* and *the visuo-spatial sketch or scratch pad.* The sketch pad was regarded as a temporary spatial memory system, and was shown to be involved in manipulating visuo-spatial imagery (Baddeley and Lieberman, 1980). The articulatory loop is a system based on inner speech that is regarded as responsible for the many speech-like characteristics of short-term memory. In the case of reading, our research has largely concentrated on the role of the articulatory loop, and only this component will be described in any detail.

The Articulatory Loop

This is the most widely explored subcomponent. It was originally formulated to account for a cluster of results that seem to suggest a strong association between verbal coding and STM. These include:

1 The phonological similarity effect: If a subject is required to repeat back a sequence of consonants or words, then the more similar in sound or articulation the items comprising the sequence are, the greater the probability of error, hence a sequence of letters with similar names such as *BTGVPD* will be harder than a dissimilar sequence such as *KYWXFR* (Conrad and Hull, 1964).

2 The word length effect: Memory span for words is a simple function of their spoken duration; hence most subjects would probably manage to repeat back a sequence such as *sum wit harm bond day*, but would have difficulty with a sequence like *organisation university tuberculosis aluminum hippopotamus*. It proves to be the case that the crucial variable is spoken duration rather than number of syllables. Hence disyllabic words with long vowel sounds such as *Friday* and *harpoon* are less well recalled in a memory span situation than words that have short rapidly spoken vowels, such as *bishop* and *topic* (Baddeley, Thomson, and Buchanan, 1975).

3 The unattended speech effect: If a subject is required to remember a sequence of visually presented items, then his performance will be markedly impaired if irrele-

vant material is spoken at the same time (Colle and Welsh, 1976). The important feature of the irrelevant material is its speech-like character. Irrelevant white noise does not produce the effect, but provided the material is spoken, its meaning is unimportant, with nonsense syllables being just as disruptive of performance as words (Salame and Baddeley, 1982).

4 Articulatory suppression: If subjects are prevented from subvocally rehearsing material by requiring them to utter some irrelevant speech sound such as the word "the", then their immediate memory span is impaired. Furthermore, provided material is presented visually, then the suppression of subvocal rehearsal abolishes the phonological similarity effect (Murray, 1968), the word-length effect (Baddeley, Thomson, and Buchanan, 1975) and the effect of irrelevant unattended speech on memory (Salame and Baddeley, 1982).

All these phenomena can be explained relatively simply by assuming a separate articulatory loop that is capable of holding spoken material. In the case of visually presented items, registration in this system will occur only if the subject subvocally articulates the material. In the case of auditory presentation, however, registration in the store is obligatory, hence irrelevant spoken material will disrupt performance even though the subject is attempting to ignore it. The process of subvocal rehearsal allows the subject to take advantage of this store in two ways. First, by subvocal rehearsal he is able to revive fading memory traces within the store. Second, by articulating visually presented items, he can supplement the visual store with a more durable phonological memory trace.

The Articulatory Loop and Fluent Reading

A perennial problem in discussions of reading is that of the role of subvocal speech. We attempted to tackle this question using some of the techniques and concepts developed in studying the articulatory loop. One of these was to attempt to study speech coding by manipulating the phonological similarity within the material to be read. We did indeed find that subjects took longer to decide on the grammaticality of a sentence such as *Rude Jude chewed crude stewed food*, as opposed to *Rude chewed Jude crude stewed food*. However, we were not able to rule out the possibility that this effect might stem from visual similarity within such sentences. Although one can get occasional words in which sound and spelling are sufficiently divergent to allow them to be studied separately, the structure of English simply does not allow one to produce sentences of such words (Baddeley and Lewis, 1981).

A more straightforward set of results was obtained from a series of experiements studying the effects of articulatory suppression on fluent reading (Baddeley, Eldridge, and Lewis, 1981). In one experiment we required our subjects to read silently passages of prose taken from a travel book. Their task was to detect occasional errors, an error being the reversal of the order of two words hence *he was very rich* might be transformed to *he very was rich.* In one condition, subvocal articulation was suppressed by requiring the subject to repeat the word *the* at a rate of about 3-4 per second. Performance was compared with a control condition in which subjects were free to indulge in whatever subvocal activity they wished. Finally, in order to control for the possibility that performing any supplementary task will impair performance, we included a tapping condition in which the subject was required to tap with a pencil, again at a rate of 3-4 times per second.

The results of this experiment are shown in Table I, from which it is clear that suppressing articulation substantially impairs performance ($p>.01$) while tapping led to no significant decrement ($p > .10$). In contrast to the clear effects of suppression on errors, however, we obtained no effect on speed. Other results indicated that articulatory suppression had no detectable influence on the processing of brief and simple sentences for which the error rate was universally low, but had a marked effect on the accuracy but not the speed of performing more complex comprehension tasks. This suggests that being free to subvocalize may be important for complex comprehension tasks. Furthermore, since speed of processing is unaffected by suppression, our results suggest that this subvocalization operates in parallel with other aspects of comprehension, providing a supplementary backup, probably one that is particularly useful when it is important to process order information accurately.

While trying the task ourselves we noted that it was still possible to "hear" the passage one was reading. We checked out this observation in a series of experiments where subjects were required to make judgements on the sound of words or nonwords. For example, subjects might have to decide whether *cayoss* sounded like a real word, or whether a word and nonword (e.g. *brude - brewed*) sounded alike. Table II shows the effect of articulatory suppression on both the speed and accuracy of performing a range of tasks involving the judgement of the sound of words or pseudowords.

We found that our subjects were quite capable of making such judgements while suppressing articulation, and that their performance was not significantly slower or less accurate. On the basis of these results we concluded that there probably exist at least two speech codes, one is involved in the articulatory loop, and helps to support short-term memory. The other, possibly analogous to an acoustic image, is sufficient to allow rhyme judgements, but does not appear to be used in short-term memory tasks (Baddeley and Lewis, 1981). A similar conclusion was reached independently by Besner on the basis of both studies of judgement of homophony under suppression (Besner, Davies, and Daniels, 1981) and by a demonstration that memory span is greater for pseudo-homophones (e.g. *frute, chane*) than for other non-words (e.g. *prute, chale*) even under conditions of articulatory suppression (Besner and Davelaar, 1982).

Our results seemed to suggest that phonological coding in reading was used sometimes, but was in fact optional. One implication of this would be that puns might be different when presented in the written and the spoken mode. A pun is essentially a play upon words in which two meanings are accessed by the same phonological pattern. They can be divided into identical puns, where the two meanings are spelt in the same way (e.g. *saw*) and others where the same sound is spelt in different ways (e.g. *cheap* and *cheep*). If reading is always accompanied by a phonological code, then it should not matter whether the spelling is or is not identical for either spoken or written puns. If on the other hand, a phonological code is optional, then one might expect to find that experienced written punsters would tend to favour identical spellings.

We therefore analysed headlines from two British daily newspapers, *The Guardian* and *The Daily Mail* for one week, categorising the large number of puns perpetrated by headline writers as either identical or non-identical. We compared these with the puns detected from a range of radio and TV programmes. Finally to obtain a baseline we analysed a set of truly awful puns published in *Famous Monsters* and perpetrated by the editorial board (Chairman D. R. Acula) in an attempt to en-

Table I. Influence of articulatory suppression and tapping on the detection of errors in prose. Data from Baddeley, Eldridge, and Lewis (1981, p. 448).

	Control	Suppression	Tapping
Misses (out of 5)	1.54	2.40	1.64
False alarms (%)	.05	.04	.07
Time/passage (s)	68.03	69.19	68.44

Table II. Effect of articulatory suppression on speed and accuracy of rhyme judgments of three types. Data from Baddeley and Lewis (1981).

	Speed (Sec/Item)		Errors (%)	
Task	Control	Suppression	Control	Suppression
Sounds like a real word, e.g. *yorn*	1.88	2.02	14.4	18.5
Word-nonword rhymes, e.g. *ocean-oshun*	1.88	1.92	6.4	6.6
Non-words rhyme, e.g. *kerm-curm*	2.34	2.34	8.4	13.3

Table III. Distribution of identical and nonidentical puns in different media[a,b]

	Identical	Nonidentical
Newspapers	68	18
Radio & TV	25	37
Monster panel	14	48

[a] $X^2 = 50.0$, d.f. = 2, p .001

[b] Excluding monster jokes: $X^2 = 23.3$, d.f. = 1, p .001

courage its readers to take part in a monster joke competition. The results of our profound and extensive research are shown in Table III, from which it appears that headline writers do appear to avoid non-identical puns, suggesting that they at least, operate on the assumption that the creation of a phonological representation in reading is by no means guaranteed (Baddeley and Lewis, 1981).

Our evidence suggests then that there are probably at least two phonological codes. Coding by articulation appears to operate in parallel with other reading processes since it does not slow down reading, and appears to increase accuracy but is probably not necessary for comprehension of gist. There is almost certainly a second phonological code which is sufficiently powerful to allow rhyme judgements, but does not appear to contribute to verbal memory.

Neuropsychology, reading, and the articulatory loop

We have recently begun to study the reading of a patient with a very pure deficit in auditory verbal STM (Vallar & Baddeley, 1984a). This patient, P.V., has impaired digit span for auditorily presented material, with relatively normal visual digit span. She shows no evidence of recoding visually presented material, with visually presented letters showing no phonological similarity effect, and her performance being unaffected by articulatory suppression. She shows no word-length effect, suggesting that she does not indulge in subvocal articulatory rehearsal, although her speech is unimpaired, and her ability to articulate is normal, as measured by her speed of counting or reciting the alphabet. When material is presented auditorily, memory span performance is poor, but she does show a phonological similarity effect. Her pattern of dysfunction is consistent with the view that the phonological storage component of the articulatory loop is present but impaired in capacity. For that reason, subvocal rehearsal ceases to be a profitable strategy, hence the lack of an effect of word length, or with visual presentation, of a phonological similarity or articulatory suppression effect.

In a subsequent study we have begun to investigate her capacity for comprehending both spoken and written language (Vallar & Baddeley, 1984b). Her phonological processing of spoken or written items proved to be well within the normal range as measured by phonological discrimination, assignment of stress to words and rhyme judgment. She was capable of understanding individual words and short sentences, but was poor at detecting errors in complex sentences for which preservation of the specific wording was necessary for understanding. The crucial factor proved not to be length since she found no difficulty in classifying as erroneous a sentence such as *It is true that physicians comprise a profession that is manufactured in factories, from time to time.* However, she was performing virtually at chance in detecting errors in sentences of the following kind: *The world divides the equator into two hemispheres, the northern and the southern* or *One could reasonably claim that sailors are often lived on by ships of various kinds.*

The sentences which she can handle can typically be verified by checking the extent to which the subject and the predicate are plausibly semantically related whereas for sentences of the second kind, retention of specific wording is necessary. Further experiments are currently planned to investigate in greater detail the nature of her impairment.

An as yet unpublished study (Baddeley & Wilson, in press) has explored the role of articulation in inner speech by studying the phonological judgment and STM performance of patients who are unable to speak following brain damage, but whose capacity to comprehend and to generate language is unimpaired. Such anarthric and dysarthric patients typically show an excellent capacity for understanding and producing language. Since most have severe motor problems, language production tends to involve either a rather laborious process of pointing to letters on a letter board, or a rather more convenient device whereby a keyboard is used to produce a printed output on ticker tape. We observed excellent reading, writing, and spelling in such patients, together with clear evidence for the use of the articulatory loop. Our patients showed an effect of phonological similarity in retaining visually presented letter sequences, a word length effect, and a well preserved ability to judge whether two words or nonwords would be homophonous if pronounced. Our results therefore suggest that a capacity to articulate is not necessary for the effective functioning of the articulatory loop, indicating that in mature adults, at least, it probably depends on central rather than peripheral processes.

Working Memory and Learning to Read

We are at present in the process of attempting to use the concepts of working memory to study the process of normal and dyslexic reading. We were encouraged in this by the observation that one of the most striking features of dyslexic children is their impaired digit span (Ellis and Miles, 1981). We argued that in learning to read, a child must decode a series of visually presented letters, store the outcome of his decoding in some temporary system, and subsequently blend the contents of his store to produce a word. We suggested that the articulatory loop system would be ideally designed to assist in this (Baddeley, 1979). We suggested that as each letter is decoded by the beginning reader, it is stored in the articulatory loop, hence freeing the central executive to decode the next item. Subsequently the loop is used to help blend the decoded letter sounds and to map the blend onto a real word. We were encouraged in this suggestion by the results of Liberman, Shankweiler, Liberman, Fowler, and Fischer (1977) who report that poor readers show much less evidence of the influence of phonemic similarity than do good readers, suggesting that they are not fully utilising the articulatory loop.

In an attempt to explore this further, Ellis, Miles, Lewis, Logie, and myself have studied the memory and reading characteristics of a range of dyslexic boys. We asked first, whether they showed normal signs of utilising the articulatory loop. If they were failing to do so, then there should be no evidence of the phonological similarity, word length, or articulatory suppression effects.

We tested three groups of boys aged approximately 14 years, one from a school for dyslexics, one sample of children of the same chronological age from a normal school, and a third sample comprising children who were matched for reading age with the dyslexic boys, and hence who were somewhat younger (Ellis, Baddeley,

Table IV. Memory span performance of dyslexic and control subjects. Data from Ellis, Baddeley, Miles, and Lewis (Unpublished).

	Dyslexic group	Reading Age control group	Chronological Age Control group
N	20	20	20
Mean chronological age (yrs:months)	11:11	9:5	12:0
Mean reading age (Schonell)	9:1	9:5	12:10
Digit span	5:37	5:48	6.70
Digit span with suppression	3.70	4.27	5.17
Dissimilar word span	4.25	—	4.70
Similar word span	3.25	—	3.42
Short word span	3.88	—	4.28
Long word span	3.33	—	3.65

Miles, and Lewis, unpublished). We measured memory span for visually presented digit sequences, both with and without articulatory suppression, and auditory span for phonologically similar and dissimilar words and for long and short words. The results of these three tests are shown in Table IV.

Comparing the dyslexic group with their chronological age controls, it is clear first of all that their span is impaired, a characteristic result in the case of developmental dyslexia. Is this then because they failed to use the articulatory loop system? Surely not, since they show at least as clear an effect of articulatory suppression and phonological similarity as do either the chronological age or reading age controls. This result would seem to be at variance with reports by Liberman, Shankweiler, Liberman, Fowler, and Fischer (1977) of an absence of phonological coding in memory span performance by poor readers. It is, however, consistent with results obtained by Johnston (1982) who also found that dyslexic children exhibited apparently normal phonological coding.

A possible resolution to this paradox is offered by the work of Siegel and Linder (1984) who note that poor readers show evidence of impaired phonological coding, provided they are tested at a sufficiently early age, after which they appear to use the articulatory loop system in a normal way. Our dyslexic subjects were several years older than those studied by Lieberman et al. This suggests a developmental lag in the use of the articulatory loop for visually presented material. It is perhaps worth noting at this point that Hitch and Halliday (1983) report that young children show evidence of using the articulatory loop from a very early age when material is presented auditorily, but that with visual presentation, the use of a subvocal rehearsal strategy does not occur for 6 and 8 year olds, but is clearly present by the age of 10. This result suggests that it might have been wiser in our own study to have used visual presentation to study the phonological and word length effects, as well as the effects of articulatory suppression. Nevertheless, the fact that the effect of suppression remains strong in this group indicates that our subjects had, by the time we tested them at least, reached a point at which they were using the articulatory loop system in a relatively normal manner.

Does this then rule out an articulatory loop deficit as a possible explanation of developmental dyslexia? Clearly not, for two reasons. First, the children that we tested had all been attempting to learn to read for several years; it is therefore possible that during a critical earlier period, their failure to use the articulatory loop adequately may have handicapped them, producing a lag from which they have not yet recovered. This view would imply that once the articulatory loop had become functional, the difference between dyslexics and controls would begin to diminish, a reassuring but unfortunately not altogether convincing view. In fact, there was clear evidence that our subjects were continuing to have considerable difficulty in reading although they were obviously making progress, and in general the evidence suggests that severe developmental dyslexics continue to be somewhat handicapped into adulthood; although reading itself tends to improve particularly with remedial training, some problems of spelling and composition often persist (Zangwill, personal communication).

Further evidence to suggest a continuing impairment comes from two aspects of our data. First of all, the overall memory span of our subjects continued to be impaired, despite the fact that they were clearly using the articulatory loop. In fact their level of performance was approximately that of the younger children having a comparable reading age. A second source of evidence comes from a detailed correlation analysis of the various characteristics of our dyslexic sample and their reading age controls (Logie, Baddeley, and Ellis, in preparation). This correlated accuracy of reading with a number of other variables. The two best predictors of reading performance were memory span for visually presented digits under nonsuppression conditions, the one situation in which articulatory rehearsal of nonauditory material is crucial, and speed of articulation. This was measured by requiring the subject to count from one to ten five successive times as rapidly as possible ($r = -.43$, $p > .02$ and $r = .40$, $p > .05$ respectively). It remains plausible then that although our subjects had begun to use the articulatory loop in a normal way for retention of verbal material, its efficiency of operation may still have been impaired.

While testing these children, it became clear that immediate memory is indeed a major factor, at least in reading words that are at the limit of the child's capability. One could often hear the child subvocalising, and adopting a strategy whereby each individual letter is sounded out and stored sequentially. When the child comes to the end of the word, he attempts to recall the letter sounds and blend them into a single sequence. He then attempts to map this onto a known word. For instance the word *mad* might be sounded out "muh"-"ah"-"duh", with the three sounds blended to produce "muahd", followed by an apparent recognition of the word and an appropriate pronunciation. A particularly clear example of this occurred in the case of one subject, a 12-year-old boy of normal intelligence with a memory span of only three items. One could often hear him spell out the individual letters of a four- or five-letter word, often getting each sound correct, only to find that by the time he had read the last letter, the first letter had been forgotten, requiring him to enter the cycle once more. He was a persistent child, and would often continue for 90 seconds or more before giving up and attempting to produce something approximating some combination of the sounds he had generated.

However, given a child with a reasonable memory span and simple regular words this can be a highly effective strategy. Even for a normal child, however, it is open to two major problems.

The first problem stems from the irregularity of English, and in particular cases where later letters determine the pronunciation of earlier. Terminal *e*'s are a good example of this, since they may present the child with the problem of back-tracking in order to change the encoding of an earlier vowel, before going on to blend (e.g. the *a* in *mad* versus *made*). This backtracking process is clearly likely to cause forgetting of both the sounds and their order which in turn will make accurate reading difficult.

A second problem stems from the fact that it is difficult to encode the sound of an isolated consonant. The strategy here is usually to append a dummy *uh* sound, so that *bring* becomes *buh ruh i nuh guh*. As we know from the phonological similarity effect, a string of items that sound alike is very hard to remember correctly. Adding 'uh' to each consonant will thus make it hard for the child to remember the letters he has read. It is therefore not surprising that our children often appeared to decode the letters correctly but subsequently left letters out or changed their order in coming up with their final blend (e.g. *sing* for *sting*). The resulting errors might seem like visual misperceptions, and we suspect that many errors that are classified in subsequent analysis as visual errors are in fact a result of short-term forgetting.

If our observations prove to be correct, then it suggests that the teaching of reading could be improved by adopting two simple strategies. The first of these is to encourage the child to scan each new word looking for irregularities such as terminal *e*'s, before starting to decode it in detail. This will avoid the problem of having to backtrack and change the previous vowel sound. The second strategy suggests that children should be strongly discouraged from decoding individual consonants. Instead, they should decode consonant-vowel pairs or clusters; this should have two advantages. First it will reduce the number of chunks to be held in memory, hence a word like *clock* becomes two clusters rather than five separate letter sounds. Secondly, this strategy will minimise the phonological similarity effect by avoiding the production of sequences in which all the consonant names contain the same "uh" sound. Both of these should enhance the memory component substantially and would, we predict, lead to better reading in both normal and dyslexic children.

Conclusion

The concept of working memory represents an attempt to bridge the gap between the precise analysis of laboratory tasks, such as immediate memory span, and such important but more general cognitive skills as reading, understanding, and reasoning. I hope that in doing so, it will help us tackle these complex but important cognitive skills: I am sure that whether successful or not, the attempt will enrich our understanding of human memory.

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Reading Ability and Knowledge of Orthographic Structure

Dominic W. Massaro
University of California, Santa Cruz

It has been well-documented that orthographic structure (spelling contraints) contributes to the perceptual processing of letter strings. The present paper continues this study by exploring the relationship between utilization of orthographic structure and reading ability. Fourth-graders of varying reading ability were given pairs of letter strings and asked to pick the string that most resembles English spelling. The letter strings were varied systematically in terms of lexical status, frequency of sublexical patterns, and rule-based regularity. The results revealed a significant positive relationship between reading ability and appropriate decisions about English spelling. Some constraints in English spelling are mentioned along with some suggestions about how classroom practice might be modified to facilitate the child's understanding of orthographic structure.

Reading involves the integration of the visual patterns on a page of text with the reader's knowledge. Students of reading seek to understand the processes involved in evaluating the visual patterns, the nature of the knowledge sources, and how the knowledge sources are integrated with visual processing. It is generally accepted that sentential constraints in the form of semantic and syntactic information are utilized in reading. Although it is not as obvious, knowledge of orthographic structure (the constraints or redundancy of written language) is also utilized in letter and word recognition.

The utilization of orthographic redundancy is not necessary for accurate letter recognition, but it allows reading to be much more efficient. Even though the page of text appears to be clear to the reader, all readers have tunnel vision. Only six or eight characters to the right and left of fixation are perfectly legible. In addition, the short duration of an eye fixation may not allow complete processing of all of the potentially legible letters. Orthographic structure supplements the relatively limited visual information available to the reader in a given eye fixation (Massaro, 1975).

Given that orthographic structure facilitates reading, it is important to describe the reader's form of knowledge of this structure. In previous work, Venezky and Massaro (1979) have distinguished between two categories of descriptions: statistical redundancy and rule-governed regularity. The first describes the reader's knowledge in terms of the frequencies of occurrence of letters and letter sequences in written

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Author's address: Department of Psychology, University of California, Santa Cruz, CA 95064.

text. According to the second description, the reader acquires certain rules about the nature of letter patterns in words. The rules can be described by phonological constraints in spoken English and scribal conventions in the transcription of spoken English into writing.

One method of testing various descriptions of the reader's knowledge of orthographic structure is to ask the reader to process novel letter strings. In our work (Massaro, Venezky, & Taylor, 1979; Massaro, Taylor, Venezky, Jastrzembski, & Lucas, 1980; Massaro, Jastrzembski, & Lucas, 1981) we begin with real words and make anagrams of them to create strings that vary systematically according to various descriptions of orthographic structure. We have used two basic tasks in the study of the reader's processing of these letter strings. The first involves perceptual recognition of the letter strings, whereas the second requires an overt judgment about the orthographic structure of the strings. In a protracted series of experiments, we have found large effects of orthographic structure in both perceptual recognition and overt judgment tasks. Given these positive results, we were encouraged to assess how knowledge of orthgraphic structure relates to reading ability and how this knowledge develops over the time course of children learning to read.

Massaro and Taylor (1980) carried out a perceptual recognition task with college sophomores. A large introductory class in psychology was given the Nelson-Denny (1973) reading test. Students scoring in the top 15 percent were contrasted with their peers scoring in the bottom 15 percent of the sample. Although there was a large contribution of orthographic structure to perceptual recognition, this contribution was identical for good and poor readers. These adult readers appear to have mastered the utilization of orthographic structure in letter and word recognition even though they vary enormously in reading ability.

Three groups of sixth graders and one group of college students participated in a second experiment (Massaro & Taylor, 1980). Based on the comprehension subtest of the Gates-MacGinite (1965) reading test, the mean comprehension grade level for three groups of sixth graders was 5.0, 7.8, and 11.9, respectively. The effect of orthographic structure on perceptual recognition was 16 percent for adults, 10 percent for the good and average sixth-grade readers, and only 6 percent for the poor readers. This substantial interaction was not statistically significant because of the large range of orthographic structure effects observed within each of the four groups of readers. However, post hoc correlations between various descriptions of orthographic structure and performance on the 200 test items revealed significant differences due to reading level. A frequency-based description correlated .48, .46, .35, and .28, respectively, for the adults, good, medium, and poor sixth-grade readers. A description based on rule-governed regularity also discriminated among the four groups of readers. These experiments provide some evidence that the utilization of orthographic structure may be related to reading ability, but only for young readers.

In another study, Massaro and Hestand (1983) studied how the acquisition of knowledge of orthographic structure relates to grade level and reading ability as measured by the California Achievement Tests (1978). Rather than using a perceptual recognition task, an overt judgment task was utilized. The subject is shown a pair of letter strings and is asked to choose the letter string that looks more like a word. This task provides information about the extent to which knowledge of orthographic structure is available and capable of report. In each pair of items, one item did not violate any rules of a rule-governed description of orthographic structure, and the other had anywhere from one to four violations. First, second, and third graders at the end of the school year were tested. First graders averaged about 58 percent correct, second graders averaged about 69 percent correct, and third graders averaged about 79 percent correct. Performance correlated .5 with grade level. We also asked to what extent performance on our orthographic structure test varied with reading level, as measured by the California Achievement Tests. Performance correlated .66 with reading level based on vocabulary and comprehension tests. Therefore, reading level accounted for 17 percent more of the total variance than that accounted for by grade level.

Two other studies report similar results to the work in our laboratory. Allington (1978) required good and poor second and fourth graders to discriminate zero-order from fourth-order approximations to English (Miller et al., 1954). Performance was primarily a function of reading ability rather than grade level. Katz (1977) asked students to report a letter's most frequent position in a five-letter string. For example, given e________ and __ ______ e_, which string has the letter *e* in its most frequent position in five-letter words? The results provided some evidence that good fifth-grade readers are better at reporting certain constraints in written English than are their poor-reader peers.

The present experiment extends these previous studies by including a much broader range of test items in the overt judgment task. The lexical status, the frequency, and the rule-governed regularity were systematically varied to assess the degree to which these sources of information are available to fourth-grade readers. The central question is whether reading ability is correlated with knowledge of spelling constraints. The subjects are given pairs of letter strings and asked to choose which letter string most resembles English spelling. Seven types of letter strings varying in lexical status, regularity, and log bigram frequency were paired with each other in the task. Consider the six-letter strings shown in Table I. For each word there are six anagrams varying in orthographic regularity and summed log bigram frequency. In addition, the words are either high or low in word frequency. Every category was paired with every other category, and each category could be paired with itself. Subjects chose the letter string "which looked most like English spelling." The degree to which subjects can discriminate among the types of items should reveal which aspect(s) of orthographic structure is (are) consciously available and capable of report.

Table I. The seven categories of items used in the judgment task.

Category of Items	Example Letter Strings	
Words	should	magnet
Regular-Very High (R-VH)	hosuld	gemant
Regular-High (R-H)	shulod	tamgen
Regular-Low (R-L)	lohuds	nemtag
Irregular-High (I-H)	dhouls	ntagem
Irregular-Low (I-L)	louhds	nagtme
Very Irregular-Very Low (VI-VL)	dlsuoh	tmngae

Method

Subjects. Forty-four fourth-grade students from the Madison, Wisconsin, School District participated as paid subjects. Of these, the data of seven were lost due to a computer malfunction. Requests for student volunteers were mailed to all fourth graders in three Madison schools. The subjects in the experiment were those who responded to the request for participants and whose parents agreed to release their child's reading test scores. The scores were for the STEP (1977) reading test which was administered near the completion of third grade. For the 30 students included in the data analysis, the STEP scores ranged from 14 to 50, with an average score of 40.5. The experiment was conducted near the end of the fourth-grade year and lasted about 45 minutes. Each child was paid $5.00.

Stimuli. Forty words and their corresponding six types of anagrams (R-VH, R-H, R-L, I-H, I-L, and VI-VL) were selected to produce 280 letter strings. Nearly all of the regular strings had zero irregularities; all of the irregular strings had two irregularities, the very-irregular items usually had three and sometimes four irregularities. The position-sensitive summed log bigram frequency could be very high, high, and low. This frequency measure and the regularity measure were independent of one another. Therefore, one level of one variable was independent of the level of the other variable (cf. Table I).

Since there were seven categories and each category could be paired with itself, there were 28 unique pairs of categories. These pairs were sampled randomly without replacement in each block of 28 trials. The actual letter strings from each of the categories were randomly selected with replacement for each group of subjects. Eventually, each subject was presented with 420 pairs for judgment. Accordingly, there were 15 trials of each of the 28 pairs of categories. The two strings of each pair were printed in lower-case and were arranged side-by-side. Each string subtended a visual angle of 2.5 degrees with 2.1 degrees between the two strings.

Procedure. The stimulus items were generated by a DEC LSI-11 computer under software control and presented on Tektronix Monitor 604 cathode ray tubes (CRT) (see Taylor, Klitzke, & Massaro, 1978). The alphabet consisted of lower-case nonserifed letters resembling Universe 55 type font.

The children were instructed about the experiment in two phases. In the first phase, two letter strings printed on 4 x 6-inch cards were held by the experimenter. The children viewed the letter strings and each raised one of their hands to indicate whether the letter string on the left or on the right looked most like English spelling. The children were encouraged to respond quickly, but to be accurate.

In the second phase all the children in a group stood in front of a CRT and were told to perform the same task as was performed with the index cards, but to press one of two response keys located beneath the CRT. Each child in the group attempted several trials while the others and the experimenter watched. They were told to be certain to respond, guessing if necessary. All children readily adapted to the computer equipment. After each child in the group had a turn, they were led to individual subject rooms for the start of the data collection session. Each of the 420 trials began with a 250-msec fixation point, followed by the two letterstrings. Subjects selected the one of the two strings which most resembled English spelling by pressing one of two keys located beneath the string. The strings remained on the CRT until all the subjects responded, or for a maximum of four seconds. The 420 pairs were presented in one session with a five-minute break after 210 trials. The experiment lasted about 45 minutes.

Results

Three groups of readers were defined on the basis of their STEP (1977) reading test scores. There were ten children per group. Ten readers with scores between 47 and 50 made up the good group, ten readers with scores between 41 and 44 made up the average group, and the poor group was made up of readers with scores between 14 and 38. For each subject, the proportion of times that each of the seven categories was chosen as most like English over the other six categories was computed. These proportions were used as dependent variables in an analysis of variance with instructions, category type, reader group, and subjects as factors. Figure 1 presents the percentage of choices of most like English as a function of category for each of the three reader groups. There was a large decrease in choices with decreases in orthographic structure $F(6, 162) = 192$, $p > .001$. The differences between adjacent categories in Figure 1 were also a function of reader group, $F(12, 162) = 5.10$, $p > .001$. The slope of the functions decreased with decreasing reading ability. This result shows that reading ability predicted to some extent the reader's sensitivity to differences in orthographic structure.

An analysis of variance also was conducted on the reaction times of all of the choice responses. Response type was included as a factor to assess the differences in reaction times between choosing a given category as most like English relative to the

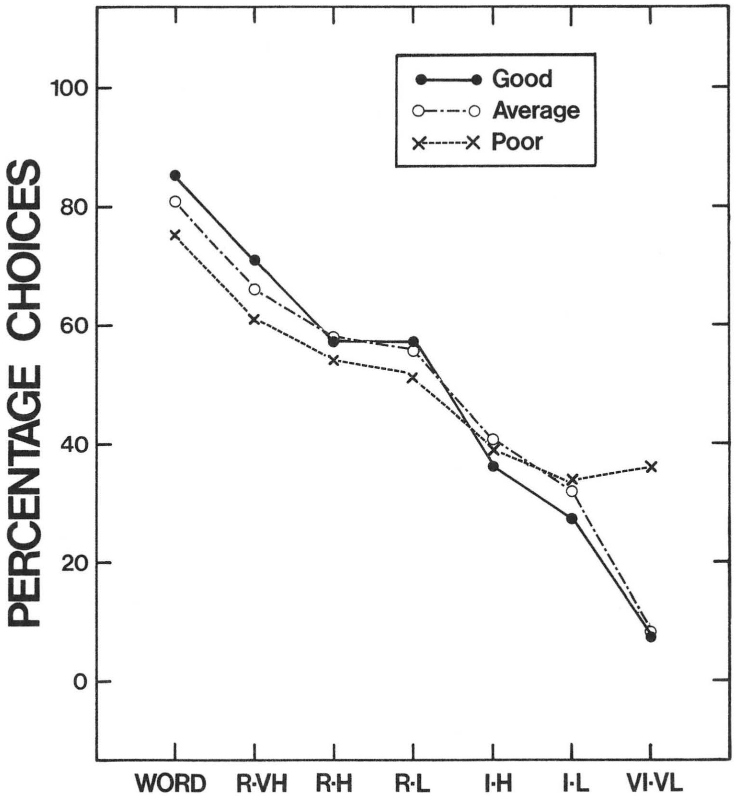
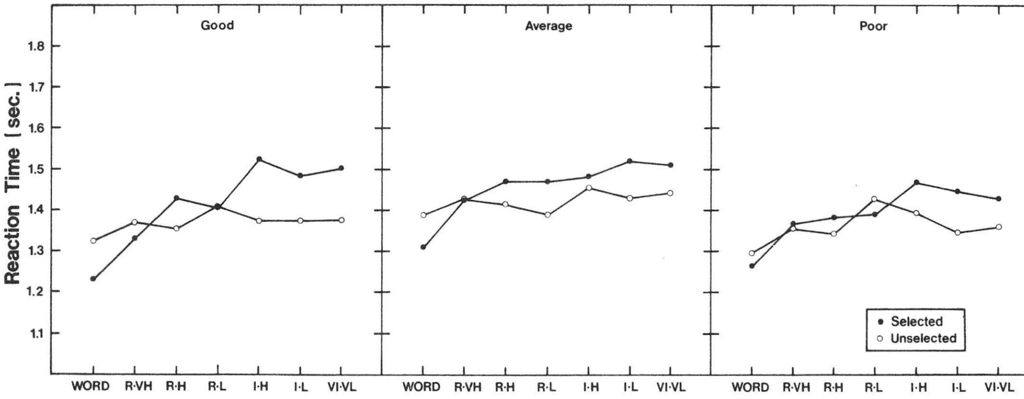


Figure 1. Percentage of choices of the letter string "that looks most like English spelling" as a function of category type, reading ability is the curve parameter.

Figure 2. Reaction times for choosing each of the category types (selected) and for choosing the alternative member of the pair (unselected) for the three levels of reading ability.



average reaction time for choosing the other six categories. As an example, the reaction times to the "word" category corresponds to all those trials having a word as one member of the test pair. The "selected" reaction time to the "word" category would be the average reaction time on those trials when a word was chosen as the item that looked most like English spelling. The "unselected" reaction time to the "word" category would be the average reaction time on those trials when the other item from any of the other six categories was chosen as the item that looked most like English spelling. Therefore, there are two reaction times for each category; the "selected" reaction time is the average time to respond with the item from that category alternative. The "unselected" reaction time is the average time to respond with the other six categories when they are paired with the designated category.

Figure 2 presents the reaction times as a function of response type, category, and reader group. "Selected" reaction times should increase with decreases in orthographic structure since it should not only be less likely but it should take longer to choose an item as most like English spelling when it is low in orthographic structure. We would not expect systematic differences in the "unselected" reaction times since they are pooled across six different categories that can have either more or less orthographic structure than the designated category. Following this expectation, reaction times increased with decreasing orthographic structure, $F(6, 162) = 22$, $p > .001$, and primarily for the selected response when that category was chosen as the item most like English, $F(6, 162) = 4.56$, $p > .001$. However, reaction times did not vary as a function of the three levels of reading ability. Accordingly, although reading ability was related to the choices of items differing in orthographic structure, it did not influence the time to respond in the task.

Discussion

Before discussing the implications of the results it is necessary to give a brief defense of using the overt judgment task as an index of the utilization of orthographic structure in letter and word recognition in reading. The overt judgment task requires decisions about English spelling after letters are recognized rather than assessing the utilization of knowledge of English spelling in letter and word recognition. Reliable judgments about English spelling in the overt judgment task does not necessarily mean that this knowledge is utilized in letter and word recognition. Similarly, readers might have and utilize knowledge in reading but may not be able to perform appropriately in the overt judgment task. The primary argument for the validity of the overt judgment task as an index of utilization of orthographic structure in reading is the high correlation between performance on the overt judgment task and performance in perceptual recognition tasks (Massaro et al., 1980, 1981). Caution in generalizing these results to natural reading is still necessary, however, since perceptual reports might not be valid measures of psychological processes (Marcel, 1984).

The present experiment, as well as those reviewed in the Introduction, demonstrates a significant relationship between reading ability and knowledge of orthographic structure. We cannot state from this research how important utilization of knowledge of orthographic structure is for good reading. Although good readers may read better because they have learned to utilize orthographic structure, it is also possible that sensitivity to orthographic structure is dependent on skilled reading. However, the significant findings encourage us in the belief that it may be worthwhile to modify classroom practice to more directly facilitate the child's understanding of orthographic structure. There are some strong constraints in English orthography and these might be taught in a game format in the classroom (Massaro & Taylor, 1980). It is encouraging that the constraints in English orthography do not change significantly with the reading level of the text. We have found very high correlations among letter and letter-pattern occurrences in texts sampled from grades three to nine (Carroll, Davies, & Richman, 1971) and texts for adult readers (Kucera & Francis, 1967). Some of the major constraints are differences in terms of where consonants and vowels occur in words. Vowel sounds are relatively infrequent in initial and final position in English words and therefore the reader can expect most words to begin and end with consonants. Overall, constraints are greatest at beginnings and ends of words. Syllable boundaries in the middle of words permit almost any pair of letters to occur in medial positions. There are also major constraints on the possible consonant and vowel clusters and where they can occur in English words.

The games involve the child in determining which letters and letter patterns occur and where they occur in English words. In one game students are given a list of letter strings and asked to search for a particular letter or cluster of letters. If the child knows where letters and letter clusters normally occur, the search through the list will be much easier. An important aspect of the game is to discuss what rules of thumb are helpful in determining where letters and letter clusters might be found. In another game the child arranges letters and letter clusters on a magnetic board to create new words. The goal is to create the words visually rather than orally. A game modeled after the overt judgment task is to categorize letter strings as possible or impossible words. Whenever a letter string is judged to be impossible, the student indicates what is wrong with it and how it might be corrected. A popular game is a version of hangman; the student is told the number of letters of a mystery word and must guess what the word is. The participant guesses one letter at a time and is shown the position(s) in the mystery word of correct guesses. Playing these games, students might be made aware of the constraints in English orthography.

A relevant issue has to do with the form of the knowledge of orthographic structure. We have described the form in terms of sublexical letter patterns and rules (Massaro et al., 1980; Venezky & Massaro, 1979), although the knowledge may be represented at only the lexical level (Baron, 1977; Brooks 1975; Glushko, 1979). A test between these two forms of representastion might be possible within the context of the training programs just described. Training programs could be devised to teach primarily sublexical rules and spelling patterns or to teach whole words. The question would be which program would lead to more substantial and rapid gains in reading skill.

In summary, our work has encouraged our belief in the important contribution of orthographic structure in reading and learning how to read. Although phonics instruction is now generally accepted, little reading instruction directly teaches orthographic structure. Classroom programs incorporating instruction on orthographic structure might allow us to assess the role this knowledge plays in learning to read.

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Is Activation of Different Codes Related to Age and Stimulus Material?

Francesca Simion, Beatrice Benelli, and Franca Tarantini
Department of Developmental and Social Psychology
University of Padova, Italy

The activation of different codes as related to age and stimulus material was studied using a same/different classification task. Two age levels (6.5 and 10.6) and two kinds of stimuli were considered. Response latencies and errors were evaluated for pairs of letters and geometrical figures, tachistoscopically presented. For both types of material same responses were given to physical identity pairs, analogue identity pairs, and name identity pairs. The results show that: (1) the nature of the stimuli affects the types of codes activated where higher-order operations are required to compare the stimuli; (2) the level of accuracy changes as a function of age for both types of stimuli.

In recent years there has been a great deal of interest in the process by which one reads words. Many of the experiments on reading have described this complex skill through a series of processing stages (LaBerge and Samuels, 1974) and have tried to differentiate the codes by which a word is represented. A visual word activates at least visual, phonetic, and semantic codes and some operations take place within each code.

According to some authors (Gibson, Shurcliff, and Yonas, 1970; Johnson, 1975), the visual code is a sufficient basis for reaching semantic levels of processing and for handling the activation of higher-level semantic analysis. Other studies seem to demonstrate that access to the semantic level of processing has to be mediated by a phonological code, that is, by a phonetic representation (Stanovitch and Bauer, 1978). To summarize, experimental evidence suggests that both types of codes—visual and phonological—play an integral part in reading processes (see for a review McCusker, Hillinger, and Bias, 1981) and that, since visually mediated access is assumed to be more rapid, it is more likely to be the representation of choice (e.g., Coltheart, Davelaar, Jonasson, and Besner, 1977; Marshall, 1976).

In order to read fluently, one must identify and discriminate among letters (Gibson, 1969). Following these considerations on the primacy of the visual code in representing letters and words and in reading, it seems reasonable to consider those studies concerned with the acquisition of letter processing, in order to have a better understanding of reading disorders. Tracing the nature of the codes activated and the

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Simion's address: Department of Psychology, University of Padova, 35137 Padova, Italy.

time-course of letter processing may help in identifying the levels at which these disorders take place.

Reading disabilities may be due to impairments in the processing of the visual code. This means that subjects may have difficulty in carrying out operations on that code, e.g., difficulties in visual orientation (for a review see, for example, Vernon, 1971). However, other studies have demonstrated that a typical reversal, such as b/d, may be the result of confusion in the production of the name code (Ellis and Miles, 1978). It is suggested that dyslexic problems in reading and spelling cannot be ascribed only to a visual code problem, but that they are attributable to deficits in the translations of visual stimuli into their name code equivalents.

While for letters isolating these two processes is difficult, non-alphanumerical stimuli are a more suitable material for differentiating the process of abstraction of visuo-spatial characteristics from that of name attribution. Two geometrical figures as, for instance, two triangles of different shapes, may be compared either on the basis of their common spatial rule or on that of their common name (Proctor, 1981). On the contrary, for two cross-case "a's" (i.e., Aa). the only rule linking the two letters is their phonetic code. The visual and phonetic codes are two independent systems working in parallel and their time-course relies on the operations carried out within each of them (Posner, 1978). For these reasons, comparison of letters and geometrical figures at different levels of processing allows us to isolate the operations carried out within each code for the two types of material and to identify the nature of the codes activated. If the phonetic code works for both types of stimuli, no difference will be found between letters and geometrical figures. On the contrary, if the phonetic code is active only for letters, a different trend related to the materials will have to be found.

The present study attempts to investigate if children at different age levels can activate different codes to compare alphanumerical and non-alphanumerical material, and if they can perform operations within each code with the same proficiency at different age levels. These questions arise from those studies that have shown differences in response latencies related to stimulus material (see Proctor, 1981) and to age (Reitsma, 1978). Posner's technique seems very suitable for testing these hypotheses since it is possible to isolate the stages of visual information processing and to define the codes on which different operations take place, both for letters (Posner and Mitchell, 1967; Posner, 1978), and for geometrical figures (Bagnara, Roncato, Simion, and Umilta, 1978).

Posner's approach rests on the temporal hierarchy found in response latencies. Reaction times (RTs) are faster when the two letters are physically identical (PI matches: AA) than when they have same shape but are different in size (analogue identity, AI matches: AA). RTs are even slower when the two letters only share the same name (name identity, NI matches: Aa).

The concept of processing levels was applied to this hierarchy where each successive level serves to produce a more abstract code. If the task requires comparison of two physically identical letters, they are classified as same on the basis of the visual code, whereas when they only share the same name, they are matched on the basis of a phonetic code. The analogue match takes place on the basis of the visual code after an operation of normalization of one of the two letters.

Our hypothesis predicts that children activate the visual code and perform automatic operations on it with the same proficiency at all age levels and independently of the type of stimulus material. This is because alphanumerical and non-alphanumerical material, visually presented, activate the visual code and the same operations take place on it when comparing both types of stimuli. Consequently, we can expect that the time difference between PI and AI matches does not vary as a function of age and stimulus material.

As far as the name level of processing is concerned, our assumption is that different codes are activated for alphanumerical and non-alphanumerical material. Letters can be compared only on the basis of the phonetic code, while pictures can be compared on a higher-order spatial code. In both cases the activation of these codes depends on learning. For letters, the correspondence between a grapheme and a phoneme is determined by the conventions of a given society (Gibson, 1969). For pictures, although the spatial rule allowing us to consider two objects as belonging to the same category is always visually present, this rule usually has to be learned.

So we can predict for both types of material an age-dependent effect at the so-called "name level". To retrieve the phonetic information (i.e., to activate the phonetic code and discover the spatial rule) we benefit from learning and practice. Consequently, we may expect that the time difference between PI and NI matches varies as a function of age for both types of stimuli.

To summarize, we predict that there will be: (1) no age-dependent effect for operations carried out on the visual code, either for letters or for figures; (2) an age-dependent effect for operations taking place on either the phonetic or the spatial code, because access to both codes depends on learning.

Method

One experiment was carried out to test these hypotheses. Children at two different age levels (6.5 and 10.6 years) were given a simultaneous same-different classification task. Both their response latencies and errors were recorded. Two types of stimuli were employed: letters and geometrical figures. Both types of stimuli were selected because they had already been tested on adults.

Subjects. Subjects were 80 children in two grade levels, 40 each in the first and fifth grades. They were tested individually. Mean age for the first graders was 6.5 (range 6.2 to 7.3) and for the fifth graders 10.6 (range 9.7 to 10.11). All the children were selected from a suburban middle-class elementary school. In each group 20 were males and 20 females. All subjects were tested towards the end of the school year. At each grade level half the subjects were tested with letters and half with geometrical figures.

Stimulus material. The stimuli were pairs of letters and geometrical figures. The style chosen for letters was Gill Extrabold (RP series of R41). Photographic negatives (35mm) of each pattern were mounted in slide-holders for tachistoscopic projection on a back projection screen. The pairs of letters were obtained by two vowels: A and E. The letters were of two different sizes and were placed one above the other so as to eliminate horizontal scanning effects (Bryden, 1966). Same responses could be given to physically identical letters (PI matches), to letters identical in shape but different in size (AI matches), and to letters that shared the same name but were printed in different typecases (NI matches). Different responses were given to letters differing in name (e.g., A E) (see Figure 1).

Thirty-two pairs required a different response and 48 a same response. Of the same stimuli, one-third were PI, one-third AI, and one-third NI matches. Uppercases and lowercases of two different sizes were used. Size, typecase, and position of the letters in the pairs were counterbalanced so that they could not be used as classification cues.

For the geometrical figures, the stimuli used were triangles and trapezoids. Eighty pairs were obtained from six geometrical figures: isosceles, scalene, and right-angled triangles and trapezoids. The stimulus material for geometrical figures is shown in Figure 2. Figures could have two possible sizes, and were placed one above the other. Physical matches were obtained by presenting two figures of the same shape and size (e.g., two scalene triangles of the same size), analogue matches were obtained with two figures of the same shape but differing in size (e.g., two right-angled triangles of different sizes), and name matches by combining two figures differing in shape (e.g., a right-angled and a scalene trapezoid).

Different pairs were obtained by combining a triangle and a trapezoid. In the 80 slides, 32 pairs required a different response, 48 a same response.

Procedure. Stimuli were back-projected on a screen in random order. They were presented binocularly and centrally for 200 msec. An acoustic signal prompted subjects to fixate a central point on the screen. Subjects were asked to judge whether the two elements of a pair were the same or different, by pressing one of the two keys on the response panel with the index fingers of both hands. Half the subjects used their right index fingers for same responses and left ones for different responses, and half followed the reverse arrangement. Pressing the keys stopped one of two electronic millisecond counters that started at the beginning of each 200-msec. exposure period. In the case of letters, subjects were instructed orally to respond same if the two letters had the same name, irrespective of size and case, and to respond different if they did not have the same name.

In the case of figures, for the younger subjects who did not know the names of the geometrical figures, the tachistoscopic task was preceded by a session during which they were taught to discriminate between the two classes of figures. Line drawings of pairs of figures were presented to the children. The classification rule was never explained to subjects, but feedback was given on the correctness of the

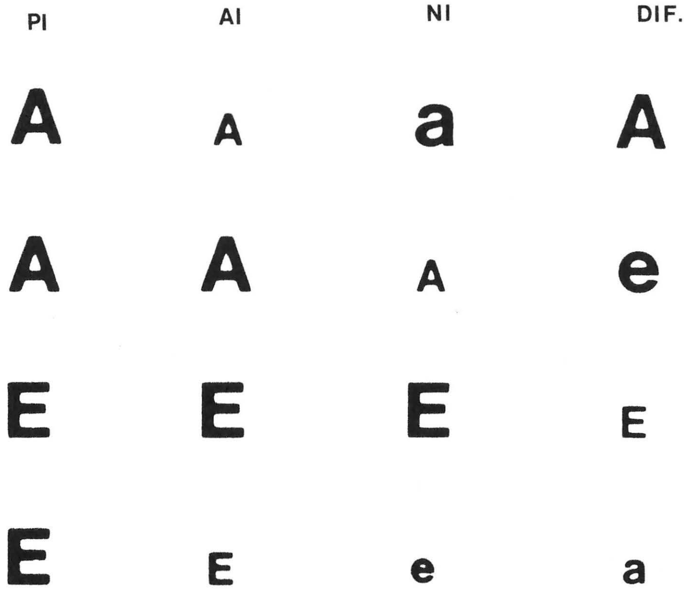
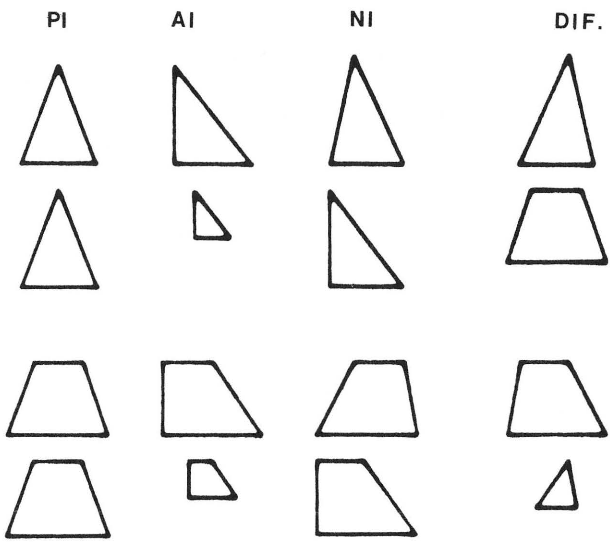


Figure 1. Examples of physical identity (PI), analogue identity (AI), name identity (NI) and different (Diff.) pairs.

Figure 2. Examples of geometrical figures employed: a) physical identity matches; b) analogue identity matches; c) name identity matches; d) different pairs.



choice. The training session lasted until subjects answered five consecutive presentations correctly. The older subjects were instructed to respond same or different on the basis of name, irrespective of shape or size. With both kinds of material the subjects were tested in one session lasting about 90 minutes. Four blocks of 20 trials each were presented, separated by a 5-min rest period. Subjects were instructed to press the keys as quickly as possible, trying to avoid errors. If they made an error or their response latency exceeded an arbitrarily set limit of 2 sec., the trial was replaced.

General Results

A summary of mean RTs and errors for both types of materials is shown in Table I. The mean same RTs were submitted to a 2 x 2 x 2 x 3 mixed ANOVA with Age (first grade vs. fifth grade), Sex (male vs. female) and Stimuli (letters vs. geometrical figures) as between subjects factors, and Type of matches (PI, AI, NI matches) as within subjects factor.

Two main effects reached statistical significance: Age, $F(1,72) = 62.51$, $p > .001$: younger children were 258 msec slower than older ones in processing the stimuli (958 vs. 710 msec). Type of match, $F(2,144) = 113.17$, $p > .001$: the three levels of processing were also found for children. Subjects were 192 msec faster to compare two physically identical stimuli than to compare two stimuli differing at the name level (744 vs. 936 msec). The analogue match was 78 msec slower than the PI match (822 vs. 744 msec), and 114 msec faster than the NI match (822 vs. 936 msec). The first-order interaction Stimuli x Type of match also reached statistical significance, $F(2,144) = 7.02$, $p > .005$). The pattern of this interaction is shown in Figure 3. This interaction is due to the different response latencies of the two types of stimuli at the three levels of processing. Letters and figures do not differ significantly at the PI level (752 msec for letters vs. 736 for figures) and at the AI level (841 msec for letters and 803 for figures). The only significant difference is at the third level of processing, i.e., the name level (990 msec for letters vs. 882 for figures). The Newman-Keuls test (Myers, 1972) was significant: $p > .01$ only for this last comparison.

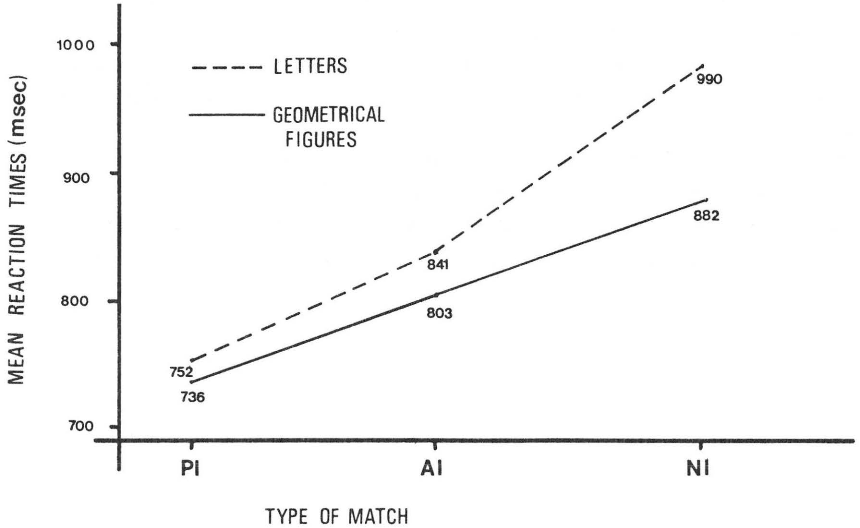
The ANOVA with the same four factors carried out on error data complements the corresponding effects in RT data (see Table 1). Two main effects are significant. The main effect Age, $F(1,72) = 8.69$, $p > .005$, shows that accuracy increases as a function of age. Older children make fewer errors than younger (6% vs. 10%). The main effect Type of match, $F(2,144) = 70.72$, $p > .001$, indicates that the percentage of errors increases as a function of levels of processing (PI = 2%; AI = 7%, NI = 15%). Also, two first-order interactions reached statistical significance. The first, Age x Type of match, $F(2,144) = 8.63$, $p > .001$, demonstrates that the percentage of errors at the third level of processing is higher for younger (19%) than for older children (10%). The second significant interaction was Stimuli x Type of match, $F(2,144) = 6.89$, $p > .005$). The percentage of errors is nearly the same at the first

Table I. Mean overall reaction times and errors as a function of Age, Stimuli, Type of match, and Type of response.

	Letters		
	First Grade	Fifth Grade	
Same			M
PI	871 (1.8%)	633 (.9%)	752 (1%)
AI	971 (5.9%)	710 (4.6%)	841 (5%)
NI	1121 (19.6%)	860 (14%)	990 (17%)
M	987 (9%)	734 (6.5%)	861 (7.7%)
Different	1188 (11.5%)	876 (7%)	1032 (9.2%)

	Geometrical Figures			
	First Grade	Fifth Grade		Overall
Same			M	
PI	852 (3.7%)	620 (3%)	736 (3%)	744 (2%)
AI	909 (9%)	697 (6.8%)	803 (8%)	822 (7%)
NI	1027 (18.4%)	738 (6.5%)	882 (12%)	936 (15%)
M	929 (10.3%)	685 (5.5%)	807 (7.9%)	834 (8%)
Different	1082 (17%)	790 (4.3%)	936 (10.6%)	984 (9.9%)

Figure 3. Mean overall reaction times as a function of Stimuli and Type of match.



two levels of processing (PI and AI matches), but at the third level a significantly higher percentage of errors for letters as compared to figures was found (17% for letters vs. 12% for figures). The Newman-Keuls test proves the significance of this difference ($p > .01$).

A three-way between subjects analysis of variance was carried out on different responses. The three factors were Sex, Age, and Stimuli (letters vs. geometrical figures). Two main effects reached statistical significance: Age, $F(1,72) = 67.81$, $p > .001$, and Stimuli, $F(1,72) = 6.76$, $p > .025$. Older children were 302 msec faster than younger (1135 msec vs. 833). Furthermore, the second main effect shows that figures are processed 96 msec faster than letters (936 msec vs. 1032). The same analysis carried out on errors showed only the significant main effect Age, $F(1,72) = 17.80$, $p > .001$. Younger children are less accurate than older (14% vs. 6%).

Conclusion

The most important result of this analysis was that Posner's paradigm was replicated for both letters and geometrical figures with children as subjects. Changes in efficiency for both letters and geometrical figures are found as a function of age for both same and different responses. Older children respond faster than younger. These results confirm previous studies on children's RTs task showing speed differences in processing visual information (for a review, see Wickens, 1974). Also the findings that same responses are faster than different is consistent with previous studies on tachistoscopic presentation carried out with children (Krueger, 1973).

The interaction between stimuli and type of match for both response latencies and errors showed that at the first two levels of processing (PI and AI matches) children have the same trends for both types of material while at the third level they differ. This finding supports our hypothesis that, independently of types of stimulus material, the visual code is automatically activated and the same operations are carried out within it. The time-course of operation of normalization does not change as a function of the different nature of the stimuli. As for the third level of processing, the so-called "name level", the results demonstrate that operations on different codes are performed for letters and geometrical figures: the former activate the phonetic code while the latter activate the visuo-spatial code. When a higher-order level of processing is required to compare letters and geometrical figures two different codes are activated and different operations take place within each of them.

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Morphological Structure and Lexical Access

Cristina Burani and Dario Salmaso
Institute of Psychology, Rome, Italy

Alfonso Caramazza
The Johns Hopkins University, Maryland

The three experiments reported in this paper addressed the question of whether the frequency of the root-morpheme of a word (e.g., *sent* from *sentire*, to hear) or the frequency of the surface form of a word (e.g., *sentito*, heard) determines decision latencies in a lexical decision task. The results indicate that both root-morpheme and word surface frequency contribute to variation in lexical decision times supporting previously reported experiments by Taft (1979). We argue that these results support a model of lexical organization that represents words in morphologically decomposed form. We also propose, however, that the address procedure for these representations does not require that the stimulus input be parsed into roots and affixes but that they can be addressed through a whole word address system.

An issue of central importance in lexical processing concerns the relationship between the mechanisms of lexical access and the morphological structure of words. Specifically, the issue concerns whether the address system of the lexical access procedure is based on whole-word or root-morpheme units, and whether a word stimulus must be parsed into its component morphemes in the course of lexical access. This issue has received considerable attention in recent years (e.g., Kempley & Morton, 1982; Forster, 1976; Manelis & Tharp, 1977), but neither the theoretical discussions nor the empirical evidence on which these discussions are based is particularly clear: The theoretical accounts of the structure of the input lexicon and the mechanisms of lexical access have remained relatively vague, and the experimental results are inconclusive.

In contrast to the issue of the specific nature of lexical access procedures which remains unsettled, the question of whether we must assume a level of representation within the lexical system at which root-morphemes and affixes are represented independently, is less problematical. There are compelling arguments and unequivocal experimental results in favor of a view of the lexicon that represents words in morphologically decomposed form (but see Butterworth, 1983). The arguments for proposing that the lexicon represents words in morphologically decomposed form are relatively straightforward, and concern the productive nature of language. Speakers of a language use words productively so that once the form class of a word has been

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Caramazza's address: Department of Psychology, Johns Hopkins University, Baltimore, MD 21218.

specified (e.g., verb) they can use the various inflected forms of that word in both language comprehension and production. Thus, if we know that *lavare* (to wash, in Italian) is a verb we would recognize *lavo* (I wash), *lavato* (washed), *lavassero* (would wash), and so on, as specific inflected forms of *lavare*, and we would be able to produce the various inflected forms of *lavare* in appropriate contexts, even if we have never seen or heard any of these specific forms. Obviously this capacity is only possible if lexical representations specify independently the root morpheme of words and the permissible affixal elements for each root morpheme.

The empirical evidence in favor of this view of the structure of the lexicon is equally compelling. Research on lexical processing with various experimental paradigms in which morphological factors have been manipulated has produced results consistent with a view of the lexicon which postulates that lexical information is represented in morphologically decomposed form. Research in word recognition (Murrell & Morton, 1974; Kempley & Morton, 1982),, lexical decision (Taft, 1979; Taft & Forster, 1975; Manelis & Tharp, 1977), word production (Mackay, 1978), speech errors in normal speakers (Garrett, 1980), and speech errors in aphasic and dyslexic patients (Caramazza & Berndt, in press) has demonstrated clearly the critical role played by morphological structure in lexical representation and lexical processing. For example, Garrett (1980) has demonstrated that the distribution of speech errors produced by normal subjects for bound-morphemes (e.g., -ed, -s) is different from that for root-morphemes (e.g., walk-). The differential distribution of bound- and root-morpheme errors has been interpreted by Garrett (1980) as evidence for a morphologically decomposed lexicon.

While there is rather compelling empirical evidence in support of a model of lexical representation that distinguishes between affixes and root-morphemes, there is a paucity of clear evidence directly relevant to the structure of the mechanisms of lexical access. What evidence there is on this latter issue is open to various interpretation. Specifically, much of the research presumably relevant to the structure of lexical access mechanisms can also be interpreted as reflecting post-access effects. This is most clearly evident in the case of the repetition effect for morphologically related words (Stanners, Neiser, Hernon, & Hall, 1979).

The repetition effect is the phenomenon in which performance in recognizing a word or in deciding whether a string of letters forms a word improves if it has been preceded by that same word for up to an hour before (Forbach, Stanners, & Hochaus, 1974). In various experiments this phenomenon has been extended to morphologically related words. Thus, for example, Murrell & Morton (1974) have shown that the recognition of a visually presented word such as CARING is facilitated by the earlier presentation of the morphologically related word CARE but not by the visually (but not morphologically) related word CARS. Results of this type have been interpreted as support for the view that the address system (logogens in Morton's model [1969]) consists of morphemic units. However, the reported result could just as easily be attributed to an effect arising at the level of post-access mechanisms—addressing the lexical entry CARE activates the morphologically related word CARING which facilitates its retrieval as a whole word at a later point in time. This ambiguity—that of attributing an effect of morphology at the level of access or post-access mechanisms—is present in all experiments in lexical processing, but especially those that have relied on the repetition effect as a means of addressing the issue of whether the units of lexical access are morphemes or whole-words (Stanners et al., 1979).

This problem of interpretation is not present in those experiments that have used "morphological" characteristics of nonwords (e.g., Taft & Forster, 1975). However, results in this area have been inconclusive (e.g. Manelis & Tharp, 1977).

Another approach that has been used to assess whether the units of lexical access are morphemes is based on the well known effect of word frequency on lexical decision (and word recognition)—decision latencies are related linearly to the logarithm of the frequency of a word (Scarborough, Cortese, & Scarborough, 1977). Various accounts have been given for the locus of the frequency effect in lexical decision. The most widely accepted view is that the threshold values (or activation gradients [Gordon, 1983]) of address units (logogens) to the lexicon are a direct function of the number of times (frequency) an address unit has been activated (Morton, 1979).

If the address units correspond to whole words, then the determining factor for decision latencies should be the frequency of individual words—surface frequency (e.g., the frequency of WALKED, CAR, RETAKEN). If, instead, the address units correspond to morphemes, then the critical factor that determines decision latencies should be the cumulative frequency of morphologically related words—root frequency (e.g., the summed frequency of TAKE, TAKEN, TAKES, and so on). Taft (1979), exploiting this logic, compared lexical decision times for words of equal surface frequency but different root frequencies and found that root frequency contributed to lexical decision latencies. He also found that surface frequency contributed to lexical decision time independently of root-morpheme frequency. He interpreted these results as evidence for a model of lexical access based on root-morpheme address units (see Forster, 1976). As we will argue later in this paper, these results are not necessarily incompatible with a whole-word address system model of lexical access. In this latter case, however, they do have rather important implications for the organization of the lexicon and the mechanism by which activation thresholds of address units are modified through exposure to morphologically related words. Clearly, then, the results reported by Taft are important and it is crucial that they be replicated. In this paper we report a series of experiments, carried out with Italian speakers, to evaluate the reliability of the results reported by Taft, as well as their generality across languages.

The experimental paradigm used in this investigation was, as in Taft's experiments, the lexical decision task. A series of letters that form either a word or a nonword is presented briefly to the subject and s/he must decide whether the letter string does or does not form a word. The logic of the research is the following. It is

Table I. Examples of three types of word stimuli used. Experiments 1a and 1b.

	1	2	3
Word type	HR-HW	HR-LW	LR-LW
Example of word	SENTITO	CHIAMAVI	FIUTAVO
Mean Root frequency	368.3	366.5	3.7
Mean Word frequency	70.7	1.7	1.7

HR = High frequency root LR = Low frequency root
HW = High frequency word LW = Low frequency word

known that reaction times in lexical decision tasks are affected by word frequency. Thus, if the word *walked* is of higher frequency than *kicked*, the time to decide that *walked* is a word should be less than the time to decide that *kicked* is a word. Furthermore, if the words *kicked* and *tested* are of equal frequency, then decision times for these two words should be the same. Consider, however, the case where the distribution of occurrence of the morphologically related words of *walked*, *kicked*, and *tested* (i.e., walk, walking, walks, kick, kicks, etc.) are such that the cumulative frequency (root-morpheme frequency) for the set *walk* (i.e., walk, walked, walking, walks) and *kick* are equal and are larger than that for *test*. What would be our expectation for decision times for the three words we have considered? Clearly, if surface frequency is the critical variable in determining decision times, then the expected pattern of reaction times is walked > kicked = tested. In contrast, if root-morpheme frequency is the determinant of decision times, then the expected pattern is walked = kicked > tested. These predictions were assessed in the following experiments.

EXPERIMENT ONE

Method

Subjects. Forty-one students attending Rome University were paid five thousand Lire, for their participation in one of the experiments. All were native speakers of Italian. No subject participated in more than one of the present experiments.

Materials. Three sets of words were used. They were all inflected verb forms, and were selected on the basis of the Bortolini, Tagliavini, & Zampolli (1971) frequency norms for Italian, which were calculated on an overall number of 500,000 occurrences. Table I presents examples of the stimuli used in the experiments and the factors considered. One set of words, exemplified in Table I by *sentito*, had both high word (surface form) and high root-morpheme frequency (HR-HW). One set of words, exemplified by *chiamavi*, had high root-morpheme frequency but low word frequency (HR-LW). The third set of words, *fiutavo*, had both low word and low root-morpheme frequency (LR-LW).

The words in the three sets were of equal mean length (mean length in letters = 6.75). The various types of inflectional suffixes were counterbalanced across groups. The test words in the two experiments were selected with the following constraints: all were regular verbs, none were prefixed, none were homographs, and none had final syllable stress. In experiments 1a and 1b we used 20 verbs in each of the three categories, for a total of 60 test items. In addition to these test items there were 60 other words of different form class (nouns, adjectives, and adverbs) that served as fillers. The filler-words were of varying frequencies, and were of the same mean length (6,75) as were the test items. Words which were prefixed, compounds, homographs, or had final syllable stress were not included in the filler set. No root-morpheme was used twice (e.g., we didn't include both a noun and a verb with the same root-morpheme).

One hundred twenty orthographically legal nonwords were included. The nonwords in these experiments were constructed by changing two or more letters of each word in the experimental list. The total experimental list included 240 items, 120 words and 120 nonwords.

The only difference between experiment 1a and 1b was that in experiment 1b a more stringent constraint in the construction of the nonwords was introduced. In experiment 1b two letters were changed in the word from which the nonword was derived. The letter change occurred ⅓ of the time in the initial, ⅓ in the medial and ⅓ in the final part of the word. In this way we made sure that the nonwords had both endings and initial parts that respected closely the distribution of suffixes and root-morphemes in the word set.

There was also one additional list which served as practice and was not scored. Fifteen words and 15 nonwords were included in this list, and they were matched for lexical type, frequency and length with items in the experimental list.

Procedure. Stimuli were displayed in upper-case letters on a black and white monitor (Phillips, model LDH 2123) controlled by an Apple computer. A subject's task in both experiments was to press one button if the letter string presented was a word and another button if it was a nonword.

Both reaction times and type of response were recorded. The subjects were given written instructions and they were told to respond as accurately and as quickly as possible. Each subject was given two blocks of 15 practice trials before being tested with the test items. Following the two blocks of practice trials, four blocks of test trials were presented. Each block had 60 test items. Test items were presented in random order, with the only constraint that no more than four words or four nonwords and no more than three experimental verbs should follow in sequence.

Each trial started with a warning signal, followed after 800 msec by the presentation of a fixation point in the center of the screen. The fixation point remained on

Table II. Latencies (in msec) and percent errors. Experiments 1a and 1b.

	HR-HW	HR-LW	LR LW
Experiment 1a	646-(3.0)	687 (3.0)	745 (9.0)
Experiment 1b	624 (3.0)	664 (6.0)	730 (15.0)

for 400 msec, after which a letter-string (word or nonword) was displayed immediately below the fixation point with the third letter of each string placed directly below the fixation point. The display of the letter-string was terminated either by the subject's response or after 2000 msec had elapsed.

Response time feedback was shown on the screen for 2000 msec if the subject responded correctly, otherwise an error signal appeared on the screen. Trials in which an incorrect response was made were not replaced. A constant interstimulus interval of 2000 msec was programmed between the letter-string display and the start of the next trial. The subject was seated 40 cm from the screen. At that distance each letter (5x7 mm) subtended a visual angle of 0.72° x 1.00°. There was a one minute rest between blocks followed by a signal that the subject could continue the experiment by a button press when ready. The experiment was conducted in a single session that lasted about 45 minutes.

Results

The results for both experiment 1a and 1b are summarized in Table II, which gives the mean latencies and percent errors for each test condition. Analyses of variance with both subject and item means as units were computed. Min F' statistics were calculated. In both experiments there was a significant effect of word type, min $F'(2.95) = 9.34$, $p > .001$ for experiment 1a; min $F'(2.94) = 13.11$, $p > .001$ for experiment 1b. Post-hoc analysis revealed further that the difference between word types HR-HW and HR-LW versus LR-LW was reliable (p at least less than .05 in all cases) in both experiments (t-tests for simple effects, Exp. 1a: HR-HW vs. LR-LW; $t(57)=3.39$; HR-LW vs. LR-LW, $t(57)=2.31$; Exp. 1b: HR-HW vs. LR-LW, $t(57)=4.92$; HR-LW vs. LR-LW, $t(60)=3.02$) while the difference between HR-HW and HR-LW was only reliable in experiment 1b (Exp. 1a: $t(57)=1.08$; Exp. 1b: $t(60)=1.88$).

The pattern of results for the error data closely paralleled those of the reaction time data, min $F'(2.90) = 3.72$, $p > .05$ for experiment 1a; min $F'(2.96) = 7.38$, $p > .001$ for experiment 1b.

The pattern of results obtained do not correspond to either of the two predicted patterns. It appears that there is an effect of both word and root morpheme frequency although the effect of word frequency is not as strong as that of root morpheme

Table III. Examples of three types of word stimuli used. Experiment 2.

	1	2	3
Word type	HR-HW	HR-LW	LR-LW
Example of word	SENTITO	SENTIVI	FIUTAVO
Mean Root frequency	351.4	351.4	3.7
Mean Word frequency	69.9	1.8	1.8

HR = High frequency root LR = Low frequency root
HW = High frequency word LW = Low frequency word

Table IV. Latencies (in msec) and percent errors. Experiment 2.

HR-HW	HR-LW	LR-LW
592 (2.0)	647 (15.0)	712 (23.0)

frequency. Before accepting this result we wanted to make sure that the difference obtained between HR-HW and HR-LW did not result from some strange selection of words such that the letter combinations for the HR-HW were more familiar than those of the HR-LW. This possibility was controlled in experiment 2.

EXPERIMENT TWO

The procedure in experiment 2 was identical to experiments 1a and 1b. The only change introduced in experiment 2 was the structure of the stimuli. In this experiment the words used in conditions HR-HW and HR-LW were selected from the same verb root (see Table III). So, for example, for the verb *sentire* whose root (*sent-*) is of high frequency, we chose two forms corresponding to a high and low surface frequency of occurrence—*sentito* has a high frequency, *sentivi* has a low frequency of occurrence. Any difference in reaction time for these two classes of words cannot be attributed to differences in the structure of the root morpheme since root morphemes are the same in the two conditions. The verbs in the LR-LW condition were a subset of those used in the first two experiments.

Method

Subjects. Subjects were 20 native Italian speakers who were students at the University of Rome. They were paid five thousand Lire for their participation in the experiment. None of these subjects had participated in either of the two previous experiments.

Materials. In this experiment we used 10 words in each of the three experimental conditions. Since words in the first two conditions had their root-morpheme in common, it was important that no subject saw both forms of the same verb. Hence, subjects were assigned randomly to one of two distinct lists: In each of the two lists 5 of the 10 words in each experimental condition were present. Thus, for example, subject 1a was assigned to list A which contained the word *sentito* while subject 1b was assigned to list B which contained the word *sentivi*. Two subjects assigned to two complementary lists constituted an experimental subject, for a total of 10 experimental subjects. Words and nonwords used as fillers were the same across lists. Each subject saw 15 experimental verbs, 36 filler words and 51 filler nonwords, for a total of 102 items.

Procedure. The same procedure used in experiments 1a and 1b was used in experiment 2. Each subject was presented with two blocks of 15 practice trials followed by two blocks of 61 test trials each.

Results

The results for experiment 2 are presented in Table IV. The pattern of results confirms that obtained in experiments 1a and 1b. There was a main effect of Type of word, min $F'(2.44) = 6.73$, $p > .005$, and again the pattern of errors paralleled the reaction time results, min $F'(2.45) = 3.82$, $p > .05$.

Post-hoc analyses confirmed the results found in experiment 1b: Both the difference between word types HR-HW and HR-LW versus LR-LW (t-tests for simple effects: HR-HW vs. LR-LW, $t(27)=3.88$; HR-LW vs. LR-LW, $t(27)=2.11$), and the difference between HR-HW and HR-LW ($t(27)=1.78$) were reliable—there is both an effect of word and root-morpheme frequency.

Discussion

The results we have reported confirm those obtained by Taft (1979). There are two significant aspects to these results. First, we have confirmed that the root-morpheme frequency of a word is a major determinant of reaction times in a lexical decision task. Second, we have confirmed that the surface frequency of a word also contributed significantly to decision latencies in lexical access. These results are compatible with the lexical access model proposed by Taft—an extension of the lexical search model proposed originally by Forster (1976). Taft's proposal is that the address system to the lexicon operates on the basis of root-morphemes. To activate a root-morpheme unit, the stimulus word must first be stripped of all affixes (both prefixes and suffixes) and a search procedure begins for the remaining root-morpheme. The search process in this model is frequency-sensitive since address units are organized by the frequency of the root-morpheme. Thus, since the frequency of a root-morpheme is determined by the cumulative frequency of morphologically related words, search times for two words of equal surface frequency but unequal root-morpheme frequency will be different—the decision time for the word with the higher root-morpheme frequency will be faster than for the word with the lower root-morpheme frequency.

The model proposed by Taft is much less clear about the mechanism that gives rise to the observed differences due to the surface frequency of words. His proposal is that once a root-morpheme entry is found in the access file, this entry provides an address for surface forms of words stored in a master lexicon. This process involves ascertaining that the root-morpheme activated in the access file plus the stripped affix(es) corresponds to a particular entry in the master lexicon. Presumably this latter process is also frequency sensitive but the bases for this claim are left unspecified in the proposed model, reducing considerably its explanatory power.

While the reported results are compatible with the search model adopted by Taft, they are *not* incompatible with an alternative formulation of the lexical access system that is based on a whole-word address system. In this alternative formulation it is assumed that the access system is based on whole-word units which address morphologically decomposed lexical representations. Thus, for example, the stimulus word *boys* would activate an access unit corresponding to the whole word *boys* which in turn would serve to address the representation BOY- and -S in the root-morpheme and grammatical morpheme lexicon, respectively—a similar proposal has been made by Manelis & Tharp (1977). To explain the reported result (and those of Taft (1979)) we must make a number of assumptions regarding the organization of the address system and the functioning of this system.

One assumption that is made is that whole-word address units are activated in a passive, logogen-like fashion (e.g., Morton, 1979; Gordon, 1983) and that the activation function (Gordon, 1983) or thresholds (Morton, 1979) are influenced directly by the number of times that these units have been activated. Thus, for example, every time the address unit for *boys* is activated, it leads to a lowering of that unit's activation threshold (or increase in its activation function). With this assumption about the structure of the address system it is possible to explain the effect of the surface frequency of a word on lexical decision times. To account for the effect of root-morpheme frequency on lexical decision times we must assume that the activation of any member of a morphologically related set of words leads to the activation of the remaining words in that set. Thus, for example, the activation of WALKED leads to the activation of WALK, WALKS, WALKING, WALKER, and WALKERS and a consequent lowering of the activation thresholds of the address units for these words. However, the magnitude of the threshold lowering is not equal for the directly activated (WALKED) and indirectly activated address units. We assume instead that there is a larger threshold lowering for the directly activated address unit than the indirectly activated units (e.g., WALK) but that the threshold values of these latter units are, nonetheless, lowered significantly. In this way we are able to account for the effect of the root-morpheme frequency on lexical decision times.

This account of the structure of the lexical access procedure forms part of a larger model of lexical processing which we have called the Addressed Morphology Model (Caramazza, Miceli, Silveri, & Laudanna, in press). In this model morphologically decomposed representations in the orthographic lexicon are addressed directly through whole-word addresses. However, various sorts of empirical evidence, as well as theoretical arguments require that this model be modified to include a procedure that allows lexical access through root-morpheme addresses (Taft & Forster, 1975; Laudanna & Caramazza, Note 1; see Caramazza et al., in press, for discussion). This modified model—the Augmented Addressed Morphology Model—allows access of lexical representation through both whole-word and root-morpheme addresses (Caramazza et al., in press).

The Augmented Addressed Morphology Model can account for the reported morphological effects in lexical decisions while proposing a whole-word address system for lexical access. By contrast, the Lexical Search Model proposed by Taft encounters difficulties in explaining several experimental results concerning lexical decisions for affixed (e.g., sender) and pseudo-affixed (e.g., sister) words. The assumption, in this latter model, that lexical access proceeds through a parsing stage in which affixes are "stripped off" a word and then the root-morpheme serves as the basis for lexical access, has not been confirmed (Rubin, Becker, Freeman, 1979; Henderson, Wallis, & Knight, 1984; Manelis & Tharp, 1977). Specifically, no support has been obtained for the hypothesized distinction between lexical decision latencies for affixed and pseudo-affixed words, suggesting that lexical access for known words proceeds through a whole-word address procedure.

In conclusion, the results we have reported confirm those reported by Taft (1979). Specifically, we have shown that both root-morpheme and surface frequency contribute to lexical decision times. In contrast to Taft, however, we do not think that these results require a lexical address system based exclusively on root-morpheme units. Instead, they are explicable within the Addressed Morphology Model that allows access of morphologically decomposed lexical representations through whole-word addresses.

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Lexical Knowledge and Word Recognition: Children's Reading of Function Words

Giovanni B. Flores d'Arcais
Department of Psychology, University of Leiden, and Max Planck Institute for Psycholinguistics, Nijmegen, The Netherlands

The paper presents a series of experiments on children's recognition of function words such as connectives and prepositions. The questions address: Is there a developmental difference in the recognition of content and function words? How available are words from the two word classes in reading? Is the difference in lexical availability of content and function words a matter of grammatical class or of meaningfulness? To what extent does the context affect the recognition of function words? Two lexical decision experiments are reported in which the availability of connectives and prepositions has been compared to that of content words. A third experiment involved a semantic categorization task, in which the subjects had to decide whether content and function words were words referring to the concept of time or not, and in which function words were decided upon much more slowly. The fourth was a probe latency experiment in which the subjects had to decide whether a given word—a connective, a preposition, a verb, or a noun—had been part of a sentence previously presented. Finally, the fifth was an experiment on word recognition in context. The results showed a lower availability of function words as compared to content words. A second finding was that this lower availability may be, at least in part, more a matter of meaningfulness than of grammatical class, function words being characterized in general by less semantic content. A third conclusion was that context facilitates recognition of function words only at a higher age.

Words unknown or unfamiliar to the reader present more difficulties than familiar words. A child's reading behavior offers an obvious and dramatic demonstration of this fact; if we ask a child already somewhat advanced in the reading acquisition process—say, a second or third grade pupil—to read a text containing unfamiliar or for him totally unknown words, we will undoubtedly notice some changes. He may stop, slow down the reading rate, start reading syllable-by-syllable or letter-by-letter, or misread the word by substituting it with a similar word, orthographically or phonetically related to it. Obvious as this statement can sound, reading skill is directly related to the lexical knowledge of the child.

A better knowledge of the developmental course of this lexical competence and of its relation to the word recognition process is of interest for a better understanding

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Author's address: Department of Psychology, University of Leiden, Leiden, The Netherlands.

of the acquisition of reading and for possible explanations of sources of certain reading difficulties in children. If lexical knowledge is an obvious and important variable in word recognition in reading, it is important to have more specific information on the availability of word classes in the child's internal lexicon, because this availability directly relates to the ease of the reading process.

In this paper I will report a few experiments on children's recognition and understanding of printed words: the experiments have compared the recognition of function words with the recognition of content words. This distinction is rather straightforward. Grammarians, linguists, and psycholinguists distinguish content and function words, sometimes called open or closed class words, or substantial and grammatical words. Open class words are the main lexical categories—such as nouns, verbs, and adjectives—which bear a clear semantic meaning. Closed class words are syntactic operators with grammatical categories such as determiners, prepositions, and conjunctions. Words belonging to this class are not very numerous. In English, in Dutch, and in Italian, for example, they are of the order of few hundreds words, as compared to the enormous size of the open class.

Function words are characterized by several syntactic, lexical, and semantic properties which make them rather different from content words. Most of these words have a poor semantic content, do not bear reference, have a clear relational function in the sentence, and are hardly used in isolation. Even for the educated adult speaker, some of these words are often difficult to define. Agrammatic patients often show particular difficulties in reading function words ("Small words are the worst" and "One of them horrid words again", Marshall and Newcombe, 1966).

Studies on content and function words.

Until recently very few psycholinguistic studies of the mental lexicon and on reading have paid attention to function words. Most studies on lexical access and on word recognition typically use as experimental stimuli nouns, which are easier to constrain and control for the design of a proper experiment. Properties such as word frequency, word length, word contour, imagery value, number of associations, etc., can with some care, at least to some extent, be controlled for with nouns. To carry out similar operations with connectives or prepositions would often mean to be left with only one or two stimulus words for an experiment or with none at all.

Behavioral evidence on differences in processing content and function words in normal subjects is scarce, and not unequivocal. Function words presented in isolation in lists are more difficult to learn than content words. However, they are learned more easily when they are embedded in sentence contexts which emphasize their role of relational words in the sentence (Glanzer, 1962). Recording of eye fixations during reading of connected text have revealed that function words attract gaze much less frequently than content words (Carpenter and Just, 1977). In reading passages of prose it is more difficult to recognize spelling errors in function than in content words (Haber and Schindler, 1981). Interesting enough, this difference holds for the same word in two contexts which selectively determine the use of the item as a function word or as a content word, such as the word *have* in the function of auxiliary or in the possessive sense (Abramovici, 1983).

Clinical or experimental work with aphasic and dyslexic patients, on the other hand, has often revealed interesting differences in the performance with open and closed class words. The evidence available in this area, once more, is by no means univocal. While agrammatics often display difficulties with function words, there are also cases of relative correspondence in the ease of processing words from either class. For example, Goodglass, Gleason, and Hyde (1971) did not find any impairment in a Broca aphasic's comprehension of directional prepositions in sentence context.

Vocabulary type seems to have an effect on the word retrieval process both in production and in comprehension (Garrett, 1982). In language production the first, most obvious, source of evidence in this direction comes from language acquisition data. Children's telegraphic speech (Brown and Bellugi, 1964) is characterized by selective omission of closed class words. Another source of evidence is the differential loss of vocabulary in aphasics: there is some indication that agrammatic patients preserve more open class items, while Wernicke are more likely to preserve words from the closed class. A third interesting type of evidence comes from analysis of spontaneous errors in linguistics production: errors consisting in the exchange of position are normally limited to open class vocabulary, while errors consisting of shifts of single elements, instead, are typical of closed class vocabulary (Garrett, 1982). All this and other evidence has been taken (for example by Garrett, 1980, 1982) as basis for the hypothesis of two distinct computational routes for the access to content and to function words. In language production closed class vocabulary would be recruited at the point in which the surface form of the sentence is being constructed, while open class vocabulary within the propositional structure underlying a sentence are being created.

Language comprehension data yield a similar picture. For example, a series of recent studies with lexical decision tasks has provided some evidence of different behavior of function and of content words. One such effect is the differential sensitivity of content and function words to frequency. In lexical decision tasks, word frequency is highly correlated with speed of decision: in fact, it is probably the best predictor of lexical decision latency. This effect, however, seems to hold only for open class word and not for closed class words (Bradley, 1978). This result is still controversial, for it could not be replicated (Gordon and Caramazza, 1982), but other effects speaking for a different computational route for open and closed class words are at hand. For example, in lexical decision tasks with non-words obtained by adding a morpheme or a suffix to an open class word (e.g., *worderty*) or to a closed class word (e.g., *sucherty*), interference effects on decision times were obtained only with open class but not with closed class words (Bradley and Garrett, 1980). Again, the evidence available speaks in favor of the existence of two functionally distinct computational routes for the access to function and to content words. Items of the two classes would be accessed through two different retrieval processes. Since closed class vocabulary items would have a special role in the procedures for assigning phrasal analyses to sentences, they would have a distinct retrieval route.

At any rate, whether the same or two different computational procedures have to be postulated for the processing of words belonging to the two classes, it remains an important question for any psychological theory of reading to try to assess in the first place whether there are systematic differences in the developmental course of word recognition for content and function words. The present work presents some evidence on the differential availability of lexical knowledge about content and function words in children and about the use of this knowledge in reading.

Meaningfulness and word recognition.

While content words tend to be rich in meaning, function words are usually void of semantic content. This variable of semantic richness or "meaningfulness" is often confounded with grammatical class.

A distinction is often made between syntactic and lexical use of function words such as prepositions. The first serves mainly a grammatical function within the sentence, while the second would carry a semantic content on its own. The same lexical unit may take different semantic contents when used in two different senses. For example, the verb *have* in the possessive and in the auxiliary use displays two different amounts of meaningfulness. The possessive sense has a specific meaning, while the auxiliary use only serves a grammatical function. Similarly, the preposition *by* has, among others, an agentive and a spatial use, and the second is intuitively "richer" in meaning than the first.

These differences also result in the performance with the same lexical unit in the two different uses. The same item seems processed differently whether it is used as a content or as a function unit (Abramovici, 1983). Another example is given by the performance of P.W., a dyslexic patient studied by Morton and Patterson (1980) who seemed capable of understanding the semantic content of function words, but not their syntactic value.

In the present author's opinion is not easy to represent the distinction as a true dichotomy. I prefer to think of a continuum with various degrees of semantic richness, and with corresponding differences in the speaker's internal lexicon. In the present work I will use the notion of "semantic richness" in a very intuitive sense, simply to indicate the presence of different amounts of semantic content in a word.

In early attempts to "measure" meaning, meaningfulness of a word was by some authors (e.g., Noble, 1952) simply defined in terms of the numbers of associations elicited by the word. More recently, semantic richness turned out an important variable in lexical decision tasks. Whaley (1978) examined the contribution of a large number of variables to the performance scores on several words in a lexical decision task, and in a factor analysis of the intercorrelations between these variables obtained an important (13% variance) factor of "semantic richness" with high loadings of meaningfulness, concreteness, imagery and age of acquisition. Another factor analytic study on 51 variables on 125 words yielded a similar factor of "imagery and meaning" with similar variables (Rubin, 1980). Thus meaningfulness seems an important variable in lexical access, which, however, has not often been taken into appropriate consideration.

Function words are semantically much poorer than content words, but within each of the two broad classes there exist large differences in semantic richness. Since many senses of the function words present a very low degree of meaningfulness, and since at any rate function words are characterized by a lower meaningfulness than the majority of content words, it may be reasonable to ask whether the processing differences between function words and content words which has been found in different experiments (e.g., Flores d'Arcais, 1981) might be related to meaningfulness rather than, or in addition to, grammatical class. This question has been addressed in the present study.

The role of context in word recognition.

Another question investigated in the present paper is the extent to which context affects children's recognition of function words. Comparing children's comprehension of complex sentences (Flores d'Arcais, 1978a) with their understanding of connectives in isolation (Flores d'Arcais, 1978b, 1981), it can be concluded that children might understand function words such as connectives when embedded in sentences, but would not yet fully comprehend the same words in isolation. An obvious implication of this conclusion is that the children would supply their lack of specific lexical knowledge by using the context and, perhaps even to a larger extent, their pragmatic knowledge of the world. This conclusion is consistent with the finding in word recognition experiments that contextual effects are larger for words which are more difficult to recognize in isolation (Stanovich and West, 1979, 1981). In the present study I have tried to determine whether function words, which were assumed to be less available than content words, would be affected by context and therefore become more easily recognizable.

Until recently a widely held belief about the effects and use of context in reading was that good readers are more effective in reading also because they make a much more efficient use of context (e.g., Smith, 1971). However, recent research has shown that poor readers use the context more than good readers (e.g., Perfetti, Goldman, and Hogeboom, 1979; Stanovich, West, and Freeman, 1981). This evidence has been convincingly interpreted on the argument that the skilled reader requires less context simply because he is good at recognizing words anyhow. The process of reading words in the good reader is highly automatized and rapid, precluding a large influence of context. Poor readers, on the other hand, would rely more on context to compensate for the lacking skill in word recognition. We can evaluate this explanation in terms of easy and difficult words rather than good and poor readers. What would be the differential use of context in recognizing words for which the children are good and poor readers, namely content and function word respectively? If the explanation is true, then we should find a larger use of context for function words than for content words. This prediction has been tested in the last experiment reported in the present chapter.

The problem.

The extent to which written word recognition of function words depends on the semantic-lexical competence available to the child at a given age is an important question for knowledge of the reading process, to which this paper intends to give a contribution.

The questions to which the present study tries to give an answer are the following. First, is there a developmental difference in word recognition for content and function words? Second, how available are words from the two word classes in the reading process? Third, to what extent does such a difference, if present, depend on word class or rather on differences in meaningfulness? Finally, to what extent does the context affect the recognition of function words in children?

The experiments reported explore with different techniques children's reading of function words. The first two are lexical decision experiments, the third a semantic categorization study, the fourth a probe latency experiment, and the fifth an experiment on word recognition in context. The first and the third experiment have been reported elsewhere (Flores d'Arcais, 1981) and will only be summarized here.

Experiment 1—Lexical decision with connectives.

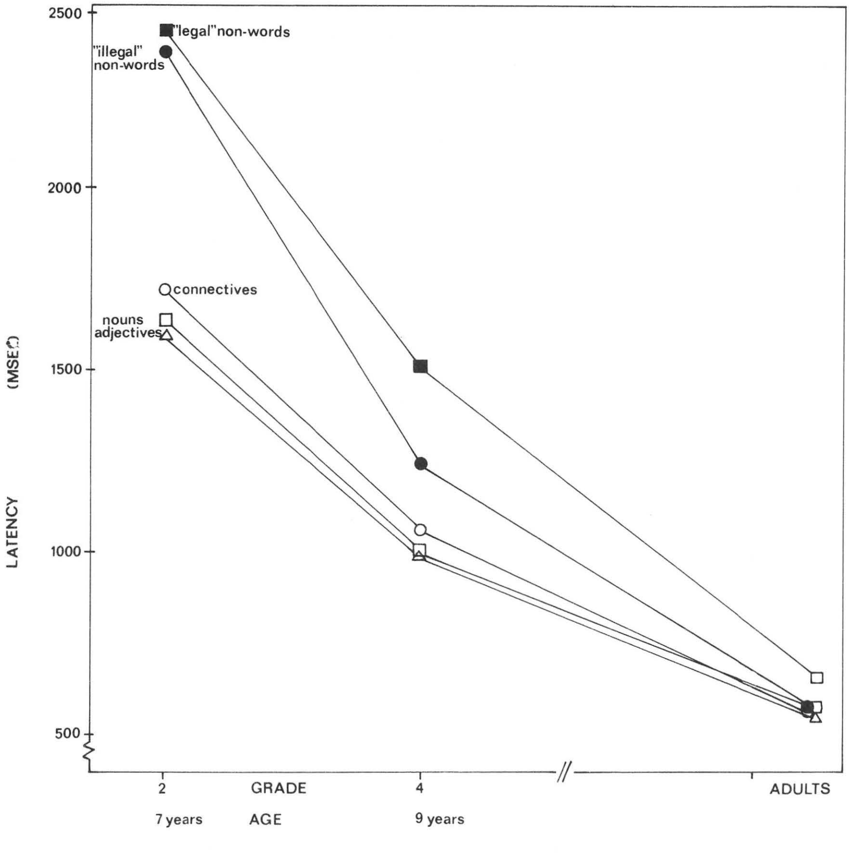
My previous work with connectives (Flores d'Arcais, 1978 a, b; 1981) has shown that the lexical knowledge about connectives develops much more slowly than one would predict on the basis of the results of experiments on the comprehension of complex sentences which include connectives. Most connectives which in context appeared to be appropriately interpreted, seemed not yet considered as meaningful word units when presented in isolation. To test this discrepancy, I used a lexical decision task, which consists of deciding whether a string of letters presented visually is, or is not, a word of the language. Of course, this means that the subjects have to be literate, and this poses obvious problems for experiments with children. Rather good results have been obtained, however, with children as young as seven years (Schvaneveldt, Ackermann, and Semlear, 1977). The dependent variables in a lexical decision task can be the number of errors and/or the latencies for the correct decisions—this latter index being almost universally the one used in studies with this procedure. Both variables can be taken as indicators of processing complexity, or about the strength with which a word has been acquired. If a child makes an error in the decision or takes very long to take the appropriate decision about a word, we may assume that he still does not know the word or does not know it well.

Method, material and subjects. The subjects were presented a display with written strings of letters. They were 19 children of second and 23 of fourth grade, approximately 7 and 9 years respectively, and 20 adults. The stimulus words were 8 nouns, 8 adjectives, and 8 connectives, 16 legal non-words and 8 illegal non-words. The 8 connectives were chosen among the most frequent 20 connectives in Dutch (Uit den Bogaard, 1973). The nouns and adjectives were matched to the connectives in frequency, length, number of syllables, and word contour.

Results. The average latencies for correct responses are reported in Figure 1. An analysis of variance on the latencies showed a significant overall effect for age and for class of words. For the children, the connectives are somewhat slower than the nouns and adjectives, which in turn require approximately the same decision times within each age level. The adults show no difference.

Discussion. If speed in making the lexical decision can be taken as an indication of the availability of the words in the mental lexicon, then it can be easily concluded that the connectives are less readily available to the child than content words.

Figure 1. Experiment 1—Average lexical decision latencies (msec) for nouns, adjectives, connectives, and for non-words.



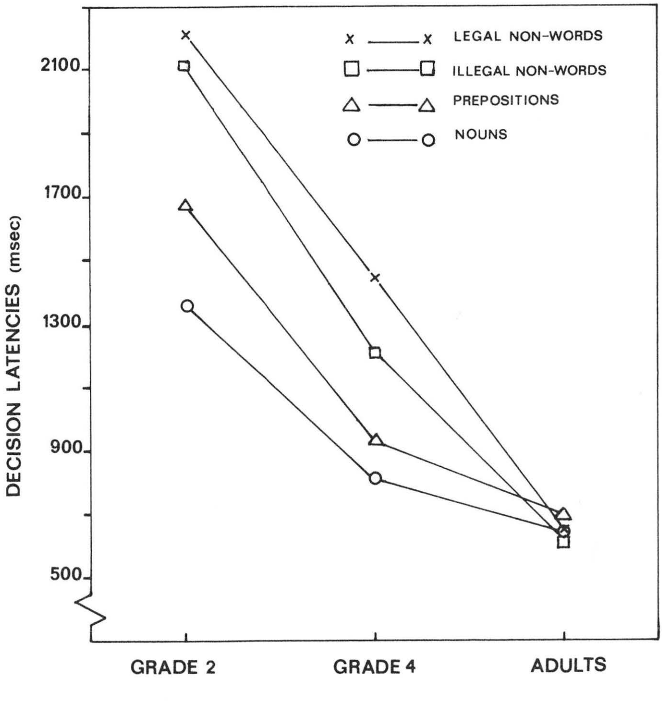
Experiment 2—Lexical decisions with prepositions.

The first experiment showed a clear difference in the speed of lexical access of connectives as compared to nouns and adjectives. In the present experiment another class of function words was considered, namely prepositions. Children start using temporal and locative prepositions rather early in language development, earlier than connectives. It was therefore of interest to see to what extent the earlier acquisitional history could affect the efficiency of the lexical access.

This experiment was essentially the same as Experiment 1. Eight Dutch prepositions were presented together with 8 nouns, 8 legal non-words, and 8 illegal non-words. The subjects were 14 children of grade 2 and 15 of grade 4, with approximate ages 7 and 9, and 15 adults. The procedure was identical to that of Experiment 1.

Results. The results, average latencies for correct responses, are reported in Figure 2. An analysis of variance carried out on these latencies showed a significant effect of age and of word class. The latencies in deciding that prepositions are words of Dutch were slower than the lexical decisions for the matched nouns for the children but not for the adults.

Figure 2. Experiment 2—Average lexical decision latencies (msec) for prepositions, nouns, and for non-words.



Discussion. The results obtained are consistent with those of the previous experiment: like connectives, prepositions are more difficult to access than nouns. The words used are normally correctly understood when functioning in an appropriate sentence, as it became evident through a small experiment using an "acting out" technique with toys, and as is known from comprehension of few spatial prepositions in children (Clark, 1973). In isolation, unlike nouns and like connectives, prepositions are difficult to access as determined by a lexical decision task.

Experiment 3—Semantic categorization: Words of time

The task of lexical decision requires the recovery of the lexical entry in the mental lexicon: one cannot decide that a letter string is a word or not if he has not been able to retrieve the appropriate lexical unit. The task is, however, rather abstract in character, for it does not specifically require the subject to consciously activate the meaning of the word. Access to the latter is obviously the most important feature of the process of word recognition in normal reading. It was therefore of interest to assess lexical access of function and content words with a technique which would specifically require the full availability of the meaning of the words. The procedure used in this experiment is of this type: a semantic category decision task, namely to decide whether a word belongs to a given lexical domain or not. In the experiment function and content words were presented with the task for the subject to decide whether they belong to the semantic-lexical domain of words of time.

Method, subjects and procedure. Sixty words were used, namely 25 words of time, and 35 from other lexical domains. The 25 words of time were of the following classes: a) 11 nouns: 3 of time measuring instruments (such as 'clock') and 8 of duration (e.g., 'year'); b) 2 adjectives; c) 6 adverbs; d) 6 connectives. Of the 35 words of other categories, 25 were matched approximately to the experimental words in class, frequency (Uit den Bogaard, 1973; de Jong, 1979), length and word contour (11 nouns, 2 adjectives, 6 adverbs, and 6 connectives), the remaining 10 were 5 nouns, 1 adjective, 2 connectives, and 2 adverbs. The words were presented one at a time on a display. The subject had to decide whether the word was a word about time or not. The subjects were 20 children each of grades 2, 4, and 6, and 20 adults.

Results. The proportion of errors on the 25 experimental words (deciding that one of those 25 words of time was not in this category) for the children and the median latency data (based on correct responses only) are presented in Figures 3 and 4. Error data and latencies show the same trend. The results of both sets of data (the proportion of errors having been transformed in arc sin) gave a significant effect for age and for category of words. The following results are particularly worth noticing: a) the decision latencies decrease regularly from grade 2 to grade 6, but still decrease further from the 6 grade to adulthood; b) the relative difficulty of the categories of words remains constant throughout the age levels.

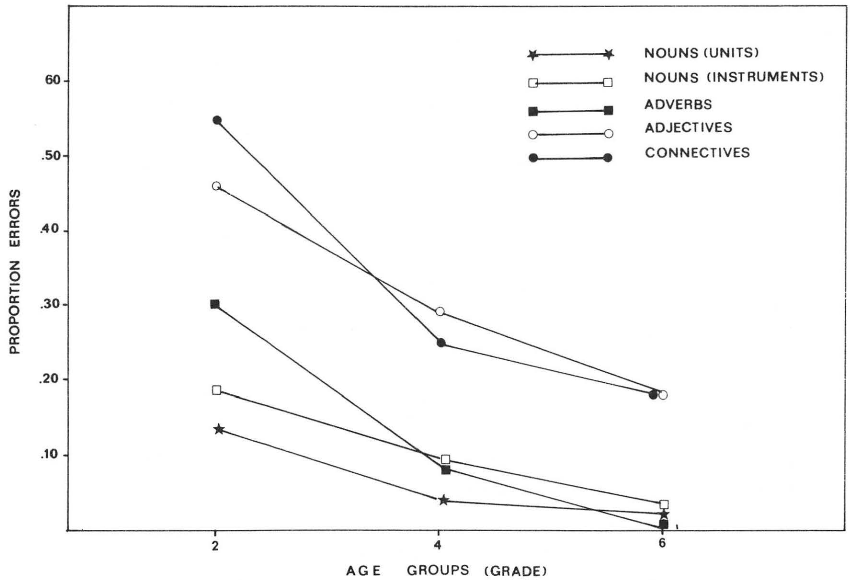
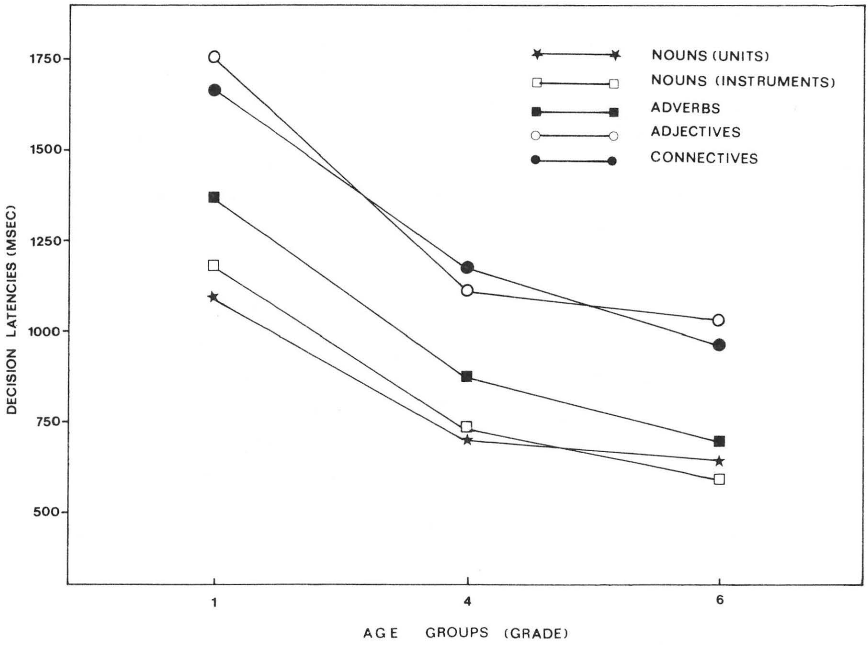


Figure 3. Experiment 3—Categorization of words of time. Proportion of semantic categorization decision errors for different word classes.

Figure 4. Experiment 3—Categorization of words of time. Average semantic decision latencies (msec) for different word classes.



Discussion. If the few words used can be taken as a good sample of the words of the different classes within the domain of the words of time—and this was not the case for the adjectives—then there is an order in the difficulty of access of the different words. Nouns are all the easiest, followed by adverbs, and the connectives by far the most difficult.

An interesting result was the relative ease of adverbs as compared to connectives. This difference in the ease of the semantic decision can be explained as due to the different semantic status of the time adverbs as compared to time connectives. Connectives are relational words; adverbs possess their own meaning. Both *now* and *while* are deictic terms, refer to the "present time"—the time in which the speaker and the hearer are communicating. However, *now* indicates a point in time: it is the time T1 in which the speaker and the addressee are, *while* indicates a time which is contemporary or parallel to the time T1. *Yesterday* is the day before the day T1, *before* is the time or action which takes place prior to another time or another action. Children's lexical knowledge seems to reflect these differences.

The developmental data obtained showed another interesting fact, namely the high consistency of the relative differences of latencies for the words used across the age levels. The most difficult words for the children are also the most difficult ones for the adults, although of course the overall performance of the latter is much better.

Experiment 4—Memory for content and for function words: A probe latency study.

This experiment investigated children's short term availability of content and function words after sentence presentation. Short term recall or recognition of words which were part of a sentence has been widely used as an indication of processing difficulty or processing capacity. For example, it is well known (Jarvella, 1970; Caplan, 1972; etc.) that words from the last clause of a sentence are recalled rather well immediately after the end of the clause, while words from previous clauses are remembered more poorly; evidence of this type has been taken as support for the "clausal hypothesis" of sentence segmentation, which holds that a sentence is kept in working memory clause-by-clause, and that once a clausal unit has been understood, working memory is cleared of surface material and the semantic information is sent to long-term memory.

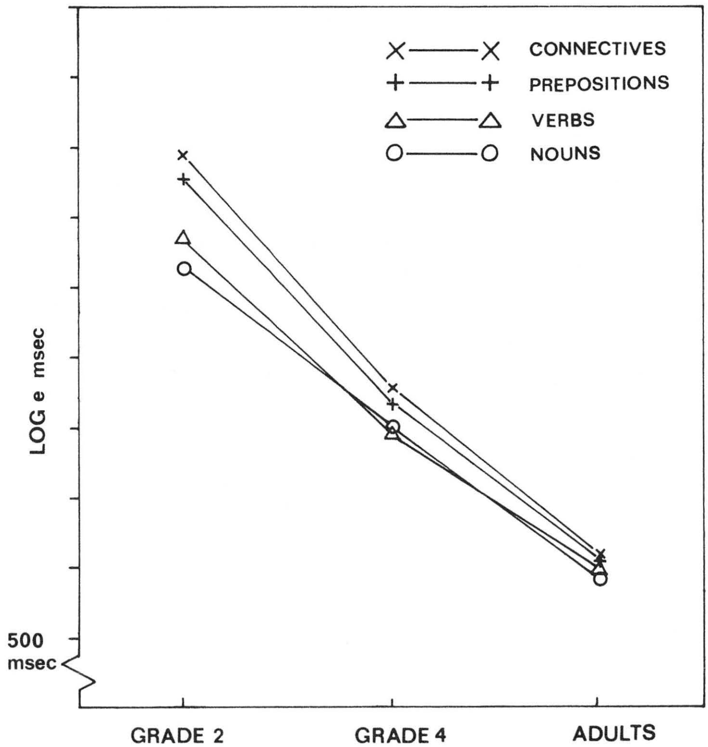
Material from sentences structurally more complex is remembered at the end of the sentence less well than material from structurally simple sentences. For example, latencies in deciding whether a word was present or not in a previously given sentence were shorter when the target word was in a main than when it was in a subordinate clause (Kornfeld, 1973).

Whether lexical availability of an individual word has an effect on recall or recognition after sentence end has, to my knowledge, not been investigated. The hypothesis tested in the present experiment was that words which are less available in the child's mental lexicon would be recalled and recognized less well after sentence presentation because these words would not be processed at the same level of the rest of the sentence. It is known from memory research carried out within the level of processing framework of Craik and Lockhart (1972), namely, that processing at a shallow level impairs memory performance (Craik and Tulving, 1975). The technique used in this study was a probe recall task, with the latency of the response being taken. The technique consists in presenting a written sentence, followed by a word which was, or not, part of the sentence presented. The task of the subject was to decide as fast as possible whether the word had been presented in the sentence. The critical words were either content or function words, and so were the distractors.

Material, method and subjects. The subjects were 16 children of grade 2 and 18 of grade 4 (the respective mean age being approximately 7.6 and 10 years) and a control group of 12 adults. They were run individually and paid for their cooperation.

The experimental material consisted of 24 sentences, with the critical words being 6 connectives, 6 prepositions, 6 nouns, and 6 verbs, approximately matched for fre-

Figure 5. Experiment 4—Memory for content and function words. Average latencies (msec) in deciding whether a word was in a sentence or not.



quency and length. For every experimental sentence half of the subjects received as the probe a function word (a connective or a preposition) the other half a content word (noun or verb). 16 filler sentences were used, the probe being a distractor (and the required response being therefore a "No"). The probability of the target was therefore .60, that of the distractor .40.

The sentence was presented one word at the time in succession from left to right, and remained visible on the display until the last word of the sentence had been presented. Half a second after an "end-of-sentence" signal the sentence disappeared from the display and a test word was displayed. The test word was either one of the words of the sentence previously presented or a distractor. The subject had simply to answer as fast as possible whether the word had been in the sentence or not, by pressing one of two response keys. A comprehension question followed some of the sentences, with probability of .40, to ensure that the subjects had read the sentences for comprehension.

Results. Figure 5 gives the latencies for the correct responses. The analysis of variance showed a significant effect of age and type of word. At both age levels the children performed significantly better with content than with function words. This difference tends to diminish with age.

The experimental words were rated by 4 judges for their "semantic richness", defined rather informally as the "amount of semantic content carried by a word in absence of contextual information" and through a series of examples. Not surprisingly, the ratings of content words were much higher than those of function words. Within the set of function words the ratings showed a large variability, with words such as *before* being rated higher in meaningfulness than words such as *although*. If we compare the average meaningfulness ratings of the 12 function words with the proportions of recall and with the average latencies in the present probe recall task, we find that the less meaningful words have elicited more errors and longer latencies. The correlation of meaningfulness and probe response times was -.75, an indication of a strong tendency to respond more slowly to less meaningful words. This holds much less for content words ($r = -.31$). Unfortunately, it is very difficult to match content and function words in meaningfulness, especially if one tries to match the words for frequency. Such an attempt, moreover, has not been a guiding principle in the selection of the material in the present experiment, as the decision to carry out the analysis here described was taken only after the experiment was over.

Discussion. The data of the experiment have shown that content words are more available immediately after sentence presentation than are function words. Not all surface aspects of the sentence are therefore available equally well: there is a selective difference which favors content words over function words. If we look more closely at the function words used, we find that words with a richer semantic content are recalled better than syntactic function words. The data, in other words, reveal a role of both grammatical class and of semantic richness in word recall.

Experiment 5—Word recognition in context.

The experiments reported so far have shown that in the mental lexicon of the child function words are less available than content words, and that short term availability of the latter ones immediately after sentence presentation is better than availability of function words. Both in isolation and in sentence, then, function words—and words that are less meaningful—are somewhat disfavored in children's reading behavior.

As briefly discussed in the introduction, sentence context has been found to affect differentially the recognition of easy and of difficult words (Stanovich and West, 1981). To what extent does an appropriate sentential context affect the ease of recognition of content and function words in children? To this question I addressed the present experiment. The subjects were presented with written sentences in which a word was "masked". At the end of the sentence a contextually appropriate or an inappropriate word was presented on the display and the subject's task was simply to read it as quickly as possible.

Material, method, and subjects. The material consisted of 32 sentences of different length. Those containing connectives were two- clause sentences, those containing prepositions could be one or two clause sentences. The target words were 4 connectives, 4 prepositions, 4 nouns, and 4 verbs. The target nouns and verbs were approximately matched in length, frequency, and word contour to the target connectives and prepositions.

The sentences were selected on the basis of ratings of about hundred sentences: a group of 6 judges rated on a 5 point scale the appropriateness of the words in the context sentences. The 16 experimental sentences were selected on the basis of high—and uniform across judges—appropriateness scores. A set of control material consisted of 16 complete sentences and the same target words bearing no relation to the sentence. Experimental and control sentences were presented in a completely random order, with some constraints to avoid presentation of the same target words within a block of 6 sentences.

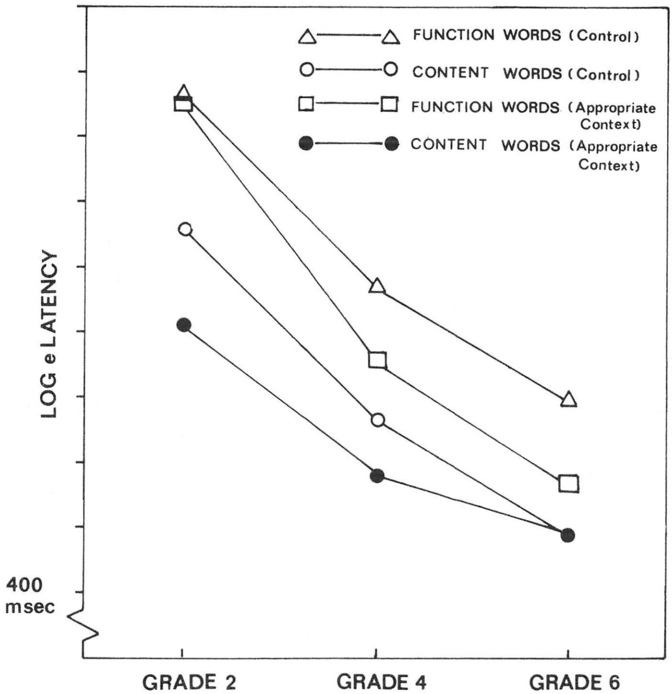
The sentences were displayed by a PDP 11/20 one word at the time on a display. The words were presented from left to right at a rate of 200 msec per word and remained visible until the end of the trial. The target word was substituted by a "word" composed by a series of Xs—its length always being the same.

The subjects were 16, 14, and 17 children, respectively, from grades 2, 4, and 6. The subjects first read the sentence by pressing the key and obtaining in this way the succession of words on the display. They were instructed to "read" as fast as possible and to go on when the "masked" word was shown. At the end of the sentence a word was displayed next to a bar which was present during the reading phase. The subject had to read the word as fast as possible, and the latencies between onset of the word on the display and the onset of the subject's verbal response was measured through a voice operated relay and recorded by the computer. The children were requested to be sure to have "ready" the whole word before starting uttering it, and received several trials of exercise, in which they were discouraged to start uttering syllables or half words or non verbal expressions which could stop the voice operated relay.

Results. Figure 6 shows the average latencies (for the correct naming only, the data associated with errors in reading having been discarded) for the function and for the content words with the context and without appropriate context (the control condition). The results can be summarized as follows: (a) Content words are named faster than function words: there is a clear difference in the latency of recognition of content and function words. (b) The context affects recognition of content words at a lower age and function words more at a higher age.

The latencies have been submitted to an analysis of variance with class of words, context, and age as factors. All three factors turned out to have a significant effect on speed of recognition. The interactions between age and context, and between age and class of words were both significant, and so was the interaction between age, class of words, and context.

Figure 6. Experiment 5—Word recognition in context. Average naming latencies (msec) for content and function words.



As in the previous experiment, ratings of meaningfulness have been obtained by 6 judges for the experimental words, and again the content words scored by and large higher meaningfulness ratings than function words. In an attempt to examine the effect of meaningfulness on the speed of word naming, the words of the two classes, function and content class, were given a score of 1 when above the median average rating, while a score of 0 was attributed to the words below the median rating in meaningfulness. An analysis of variance was run on the data so dichotomized, with age, content, type of class, and meaningfulness as factors in a 3 x 2 x 2 x 2 design. Meaningfulness showed some effect, but did not reach significance ($p = .11$). However, the interactions of meaningfulness with class of words and with age were both significant, and so was the age by word class by meaningfulness interaction. These results, together with the single comparisons among group means performed on the basis of the results of the analysis of variance indicate that meaningfulness had affected children's performance with function words, while it did not much affect the performance with content words.

These results have to be taken with a word of caution, for the ratings have been obtained after the experiments, and the distributions of the ratings were far from satisfactory. Also, the experimental words have not been selected on the basis of meaningfulness and the words of the two classes have not been matched on this variable. However, within these limits, it seems possible to conclude that the poorer performance with function words can, at least to some extent, be related to meaningfulness and not only to grammatical class.

Discussion. The first important result of this experiment was the fact that at all age levels content words are named better than function words. The difference in the ease of recognition between the two classes of words decreases with age, as is shown by the significant interaction between age and word class, but is still present at the age of about 12-13 years. Content words seem more "available" for recognition than function words. A second conclusion is that this difference might be not so much a matter of grammatical class as of meaningfulness. A third intriguing finding was the differential effect of context at the different age levels for function and for content words. A prime sentence affects differentially the speed of word naming depending on age, and on word class. It seems that recognition of function words is facilitated more by context in older children than in young ones. This result can be interpreted as follows. Context can improve word recognition when the words are already somewhat available. This is the case of content words for small children, while when function words are presented there is only space for facilitation at an older age.

General discussion.

The experiments discussed in this paper have offered some interesting information about the lexical availability and use of function words in children's reading. Connectives and prepositions take longer (and elicit more errors) in a lexical decision task than content words such as nouns or adjectives. Connectives turn out poorly also in a semantic categorization task. These results can be taken as an indication of lower accessibility of these words in the child's internal lexicon.

Even in context function words are less directly available, as revealed by a probe recognition latency experiment and by an experiment on naming of words primed by a sentence context. Short term availability of function words after sentence presentation is worse than it is the case for content words.

Another conclusion of the present study is that the lower availability of function words can, at least in part, be a matter of meaningfulness rather than of word class only. Both grammatical class and meaningfulness turned out to contribute separately to the availability of the words in the reading process. This hypothesis deserves more attention in experiments specifically designed to face this problem. At any rate, the results of the experiments reported in the present study allow the conclusion that the distinction between open and closed class is perhaps less important for a theory on lexical access than it was thought, and that meaningfulness can be an important variable in the process of word recognition.

A third contribution is the finding that context affects differentially word recognition of the two word classes under investigation at different age levels. Younger children seem capable of using contextual cues in recognizing content words, while context does not seem to facilitate function words. These receive facilitation from context only at an older age. This result can be interpreted as indicating that context facilitates word recognition when it is possible to take some advantage of it. Performance with function words at the lower age level studied is still rather poor, and the child can make very little use of the contextual information. This interpretation, if correct, has interesting practical implications for applied research on children's reading, dyslexia, and remedial procedures.

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Structural vs. Semantic Coding in the Reading of Isolated Words by Deaf Children

Adele Cavedon, Cesare Cornoldi, and Rossana DeBeni
Institute of Psychology
University of Padova, Italy

It is well known that deaf children experience great problems in reading. The paper explores the deaf problems in reading isolated words with a continuous recognition task, including 20 "basic" words and four distractors selected for the basic words on the basis either of structural similarities (visual and phonetic) or semantic connection (a synonym or a strongly associated word). Deaf children, 11-15 years old, were compared with hearing children matched for grade (experiment one) and for age or school achievement (experiment two). Patterns of confusion, inferred by false positives, indicated that hearing children relied more on semantic properties of items and deaf children more on structural properties. This result contrasts with the idea that deaf reading difficulties are mainly related to an absence of structural processing of items and suggests that their main problem concerns a less deep coding of items during reading.

It is well known that deaf children experience great problems in reading. This deficit has been sometimes quantified for British and North-American children in terms of a reading ability development less than half that children with normal hearing (Conrad, 1977; Di Francesca, 1972, reported in Kyle, 1982). The reasons for this deficit have not been extensively studied, but the idea that it is connected to the specific acoustic-linguistic deficit of deaf people is largely accepted (Myklebust, 1964). In particular, the reading difficulties of deaf children should be connected to their lower linguistic competence and to the partial or total absence of phonological processing during reading. Phonological processes, which are often stressed as fundamental in reading, have been directly associated with the reading difficulties of the deaf (Conrad, 1972, 1979).

The present study explores the use of structural and semantic codes in deaf and hearing children. A continuous recognition task employed distractors similar to positive items, in different respects. Mark, Shankweiler, Liberman, and Fowler (1977) found that the false-positive errors for good readers in a word recognition test were considerably greater in number when the foils rhymed with the initial stimulus word than when they did not, but the rhyme/non-rhyme variable had little effect on error rates of poor readers. This result was interpreted as indicating that

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Cavedon's address: Institute of Psychology, University of Padova, Padova 35139, Italy.

good readers retain, although sometimes in an imperfect way, the phonetic information included in the words that they read, whereas poor readers tend to lose it. This result was confirmed by Byrne and Shea (1979) for poor readers and was extended by Frumkin and Anisfeld (1977) to deaf children. The study of the coding strategies of English speaking deaf children reading isolated words gives additional evidence to the acoustic and articulatory deficit hypothesis (Locke, 1978; Wallace & Corballis, 1973). Wallace and Corballis have observed that deaf children made extensive use of visual coding in the short-term processing of 4- and 5-letter sequences. A hearing group relied mainly on acoustic and articulatory coding.

As Quinn (1981:140) has observed, "several investigators have argued that the deaf child's reading difficulties may reflect his inability to access a verbal code, forcing him to rely on an inefficient visual code . . . . This hypothesis is far too simple, however, given the evidence that congenitally deaf readers may have knowledge of phonological rules . . . . While lipreading can provide only limited speech cues, given the visual similarity of different phonemes on the lips, this skill may serve as a major source of phonological information for the deaf child."

It is not completely clear how the deaf derive from lipreading either phonological or articulatory or speaking competence, but it is obvious that, by learning to speak, the deaf child acquires knowledge of the articulatory (more than of the phonetic) features of phonemes. Further, articulatory similarities between letters are somewhat comparable to phonetic similarities. It appears that deaf people can be influenced, in memory tasks, by "pronounceability" effects (see, e.g., Dodd & Hermelin, 1977). If deaf problems during reading are not related to a poor extraction of structural (mainly phonological and articulatory) features, they should related to a poorer coding at other levels, probably syntactic and semantic.

As Quinn has observed, lipreading (and oral methods which stress the relevance of lipreading) should affect the cognitive competence of deaf children. This idea, however, is not confirmed by experimental results obtained in the United States. Wallace and Corballis (1973) did not observe differences between orally and manually trained deaf children. Quinn herself (1981) did not observe any relationship between aspects of the deaf child's reading performance (in this case, regarding the sensitivity to orthographic regularities) and the type of communication method used in training. Nevertheless, it is possible that with Italian children who are for the most part trained with the oral method (in Italy there does not exist a real sign language), differences in coding processes during reading can be found. Italian oral methods attribute great importance to the observation of the external articulation of the mouth and to imitation. Further, in Italian there is a close correspondence between how a word is spelled and how it is pronounced. These two facts could imply that deaf children are affected by phonetic-articulatory similarities in the stimulus materials in a measure comparable or superior to that of the hearing children.

In the present experiments we wanted to evaluate the presence of structural, including articulatory-phonetic, processes (as opposed to semantic processes) on the basis of distractors either structurally or semantically similar to positive items, which were incorrectly recognized in a continuous recognition task by deaf and hearing children. We had two groups of "structural" distractors—i.e., of items similar to positive items with reference to their non-semantic, superficial features. One rhyming group of distractors was phonetically-articulatorily similar to positive items (sharing many letters and rhyming with them). A second group included visually similar distractors, which, by sharing many letters and the general form with the positive items, probably provoked a coding which was similar both from an articulatory and from a visual point of view. It must be remembered that Italian phonetic regularities make it difficult to find words which are written in a similar way (i.e., visually similar) but are pronounced in a different way (i.e., articulatorily dissimilar). These distractors differed from rhyming distractors principally in that they did not rhyme (as, for example, *gatto* (cat), *gesto* (gesture).

Since we intended to contrast the presence of a structural coding with a semantic coding, we introduced a corresponding number of categories of semantically similar distractors. In one category we included distractors which were synonyms of positive items; in the other category we included distractors which were strongly associated to positive items. If deaf children scarcely rely on structural properties of the items, they could be oriented towards a coding of their semantic properties. But if, when the deaf read, they also code phonetic, articulatory, and visual features of words, we expect that their structural errors will not be less than their semantic errors. Our expectation was that Italian orally-trained deaf children rely on structural features, but since their word processing is less efficient than in hearing children they are less able to rely also on semantic features of the items. Further, the two different semantic categories allowed us to evaluate the accuracy of the semantic coding on the basis of the measure of the possible difference between associated words and synonyms incorrectly recognized. In fact, the false recognition of a synonym indicates that the subject's memory has simply lost the structural properties of the item, whereas in the case of the recognised associated words, some semantic information was also lost.

Experiment 1 contrasts groups of hearing and deaf children, matching them for grade rather than for age. In fact, in the school for the deaf where the experiment was carried out, all subjects had repeated a year and so it was impossible to have a simple control group matched both for age and grade. In a preceding study it was observed that by matching the groups for grade it is possible to obtain a similar overall memory performance (Cornoldi & Sanavio, 1980).

Experiment 2 includes two groups of deaf children of different ages and introduces in the continuous recognition task a simple task requiring semantic processing.

EXPERIMENT ONE

Method

Stimulus materials. 120 items forming a single list were used; 20 of these were "basic"—the others were "distractors", i.e., words that might for various reasons be confused with a basic word. For each basic word five distractors were selected, each connected to the basic word in a different way: the repetition of the word, a word visually similar, a word visually and phonetically similar, a word strongly associated (like "mouse" for "cat"), a synonym. A word was considered visually and phonetically similar when it was of the same length and had at least the four last letters in common with the basic word (it was rhyming for hearing children) (as the Italian words *gatto* (cat) and *fatto* (fact). A word was considered visually similar to the basic word when it shared at least 60% of letters and satisfied one or more of the following conditions: sharing also at least the first or the last letter and/or a sequence of two internal letters (like the Italian words *gatto* and *gesto* (gesture). At the same time the word had to not satisfy the phonetic-articulatory criterion of rhyming, but it cannot be excluded that, having many similar letters, such words also had articulatory similarities. Similarly it cannot be excluded that phonetic distractors, having many similar letters, had visual similarities. The words were all highly frequent in the language but were also controlled with respect to the common knowledge of the vocabulary of 10 to 12-year-old deaf children (examples of the items are given in Table I.

Subjects. 17 deaf children with deficit due to factors acting before or during birth, with absence of any other handicap, and with a severe to profound hearing loss (a

Table I. Examples of Items Used in Experiments One and Two.

Basic Word	Phonetical	Visual	Semantic	Synonym
SEDIA (seat)	MEDIA (mean value)	SERVA (maid)	TAVOLO (table)	SEGGIOLA (chair)
DONO (present)	TONO (tone)	DOPO (after)	PREMIO (prize)	REGALO (gift)
GATTO (cat)	MATTO (had)	GESTO (gesture)	TOPO (mouse)	MICIO (tom-cat)
BALLO (dance)	GALLO (cock)	BAFFO (moustache)	MUSICA (music)	DANZA (hop)
VENTO (wind)	LENTO (slow)	VETRO (glass)	FREDDO (cold)	ARIA (air)

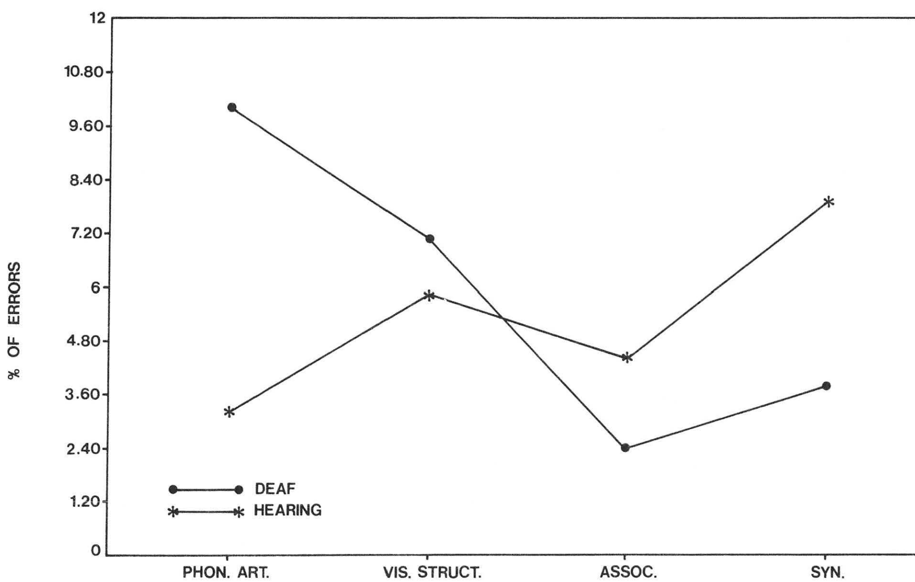
loss at the best ear superior to 70 db measured for the frequencies of 250, 500, 1000, 2000, and 4000 Hs.). The children, aged between 12 and 15, were all frequenting a special *prima media* (sixth grade) class for the deaf. The control group was formed by 17 children matched for sex, socio-economic status, and grade, and aged between 11 and 13.

Procedure. The continuous recognition task procedure which was used is characterized by the fact that presentation and test lists are mixed together. A single 120-item list including the 20 basic words, their repetitions, and the distractors was presented. Each word was printed on a separate card in italic characters. The 20 basic words appeared in the first 80 positions, whereas the corresponding repetitions and distractors were randomly dispersed after the appearance of the basic word. The mean distances between basic word and corresponding word were respectively 33.35, 32.9, 35.2, 32.75, and 31.85 words for repetitions, phonetic, visual, synonymic, and semantic association distractors. Words were individually presented at a 5 sec. rate and the subject had to indicate when a word had already appeared. Subjects were instructed to look only for exact repetitions of the words.

Results

Figure 1 shows the mean percentage of different errors for the two groups. A two-ways 2x6 ANOVA for mixed design (independent observations for the groups and

Figure 1. Mean percentage of distractors—similar to the positive items from a phonetic-articulatory, structural, associative, synonymic point of view—which were incorrectly recognized by a group of deaf children and by a control group of hearing children.



repeated observations for the kinds of errors) revealed a significant interaction groups x errors, $F(3,96)=6.6$, $p > .01$; and the difference between errors reached the .05 level of significance, $F(3,96)=2.70$. The Tukey a (Winer, 1962) procedure for a posteriori tests showed that, for the deaf group, the following differences between kinds of errors were significant: phonetic vs. semantic associations, phonetic vs. synonyms, visual vs. semantic associations and visual vs. synonyms.

Discussion

The interaction observed between groups and errors was clearly due to the fact that structural—and especially phonetic—similarities had a greater effect on the deaf children, while semantic similarities had a greater effect on the control group. The fact that the deaf also rely on a phonetic-articulatory code was confirmed by the observation that the deaf children tried often, during the task, to subvocally repeat the words. This result could also be due to the instructions given to the subjects which stressed the necessity of finding exact repetitions of items. Nevertheless, it must be observed that the deaf children—although presented a prevailing structural code—showed a good general memory performance. In fact, the mean numbers of the hits were 16.58 (82,9%) and 15.59 (77,9%) respectively for deaf and for control group, and the mean numbers of errors (false alarms) for the first presentations of the basic words were respectively .41 and .29. For controlling the role of instructions the following experiment modified the instructions introducing a very simple semantic requirement. Further, deaf subjects were differentiated for age (11-12 years vs. 13-14) with the purpose of seeing whether the phonological and articulatory awareness was more developed in older children.

EXPERIMENT TWO

Method

Stimulus materials. As in Experiment One.

Subjects. Subjects were chosen both from a school for the deaf in Padova and from normal schools where total integrations programs are carried out (such programs do not usually provide for repeating a year). Subjects were differentiated for age: 16 aged 11-12 (attending classes from the fourth to the sixth grade) and 16 aged 13-14 (attending classes from the sixth to the eighth grade). The subjects had auditory handicap comparable to those of Experiment One. All subjects had a mean hearing loss calculated at the best ear for the frequency of 250, 500, 1000, 2000, and 4000 Hz which was always superior to 75 db. For the control group we randomly selected 16 fifth-grade children. The control group was in this way matched for age with the younger deaf group, and for school achievement with the older group. Nevertheless, the deaf children revealed the usual reading comprehension deficit, obtaining at a reading test respectively the following mean scores: 4.3 for young integrated deaf, 6.44 for old integrated deaf, 2.63 for young non-integrated deaf, 2.38 for old non-integrated deaf (the score of hearing children was 7.94).

Procedure. Subjects were tested individually and at the appearance of each item had to make a particular sign when it was an animal (semantic task), and when they thought they had already read that item (memory task). To obtain both responses for the items the presentation rate was made free, but maintained overall times comparable to those of Experiment One. Subjects who were not able to carry out the semantic task were eliminated.

Results

The inclusion of the groups of deaf subjects attending different kinds of school was due both to the small groups of deaf subjects available and to the opportunity which in this way was offered to explore effects due to differences in instructional methods. Communities where seriously deaf children are integrated stress the relevance of promoting not only cognitive learning but also socialization with hearing, favouring in this way particular communication channels which the deaf can use with the hearing. Further, in these schools, failure at examinations is very infrequent. For analysing effects, due to the integration, a three-way 2x2x4 ANOVA concerning only deaf performance was carried where two variables (age, integration) concerned independent measures and the third (kind of error) concerned repeated measures, observing a significant effect due to the kind of errors, $F(3,84)=3.22$, $p > .05$, indicated about twice as many phonetic and visual errors as other kinds of errors. All the other F values were below 1. These results show that the performance observed in the deaf children in Experiment One was substantially repeated, independently from the fact that the instructions introduced a semantic requirement and independently from variables like age and the kind of school attended by the subject. For this last reason the integration variable was not considered further.

A second two-way, 3x4 ANOVA was carried out which included the control group and did not consider the integration variable, for mixed design (independent observations for the three groups, repeated observations for the kinds of errors). The only significant effect observed was the predicted effect, i.e., the interaction between groups and kinds of errors, $F(6,135)=5.7$, $p > .001$. Figure 2 shows that the effect was fundamentally due to the fact that hearing children make many synonymic errors, whereas deaf children reveal a reverse preference. Their structural errors are more frequent both with respect to semantic errors and with respect to the same categories of errors in the hearing subjects.

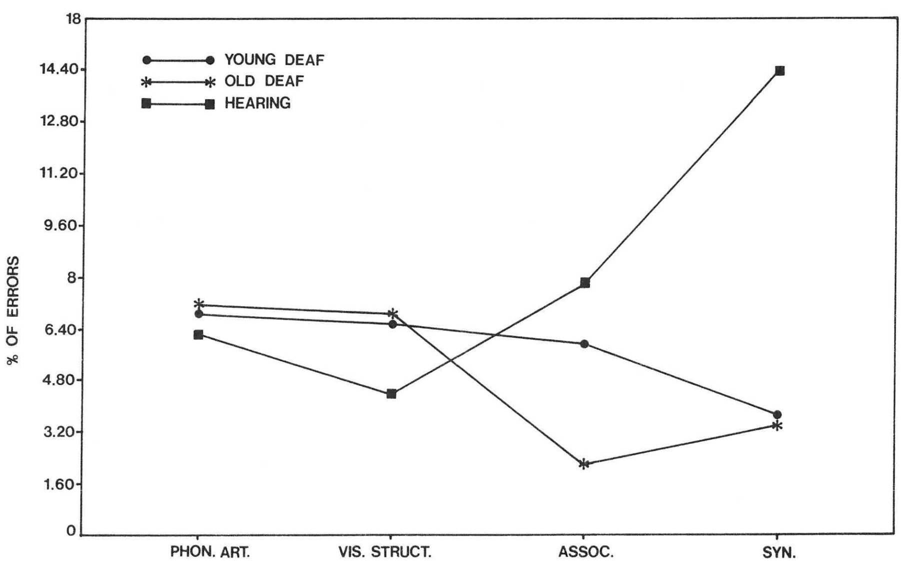
The mean numbers of hits (which were respectively 13.19 (66%) for young deaf children, 13.31 (67%) for old deaf children, 15.13 (76%) for hearing children), did not differ significantly, $F(2,45)=1.11$. Also, the mean number of false positives concerning the first presentation of basic words (which were very low in the groups, i.e., .125 (.6%) for young deaf children, .25 (2.3%) for old deaf children and .635 (3.2%) for hearing children) did not differ between groups.

Discussion

Before analysing in more detail the results obtained in these experiments, we want to discuss briefly a crucial point concerning the idea that we can deduce the prevailing code of a subject by the patterns of confusion by which he or she is especially affected. This idea occurs often in the literature (Byrne & Shea, 1979; Cermak & Butters, 1972; Frumkin & Anisfeld, 1977; etc.). Nevertheless, suppose that a subject relies only on a phonetic code but in a perfect way; he should not make phonetic errors. This is not the common case, since memory always loses some items of information, but in any event, we think that it is more prudent to interpret our results as indicating that deaf children, too, rely on structural (including phonetic-articulatory properties) of items rather than as indicating that they rely on them more than do hearing children.

Further, the clearly prevailing tendency of hearing children (with respect to deaf children) to rely on semantic properties of the items requires an explanation. Generally this difference in memory appears connected to the depth of the coding, in Craik and Lockhart's (1972) sense, and to memory performance, since memory performance is enhanced by a deeper coding (see, e.g., Jacoby & Craik, 1979). Nevertheless, in this case the groups did not differ significantly either in the number of hits or in the number of false positives, in both experiments. In other words the different processes activated by deaf and hearing children were equally functional for

Figure 2. Mean percentage of distractors—similar to the positive items from a phonetic-articulatory, structural, associative, synonymic point of view—which were incorrectly recognized by two groups of deaf children, respectively 11-12 and 13-14 years old, and by a control group of hearing children, in a continuous recognition task including a semantic requirement.



memory performance. This result could be due either to a very efficient structural code adopted by the deaf or to the fact that the deaf also have semantic processing but of a more nominalistic kind, as in the young hearing child who identifies a noun and its meaning (Piaget, 1945). It is, in fact, particularly surprising to observe the low number of synonyms incorrectly recognized by deaf children even in Experiment Two which was more semantically oriented.

These rather hypothetical considerations lead us to think that deaf reading difficulties not only cannot be attributed to an absence of phonetic-articulatory coding during reading, but also could be tentatively attributed to insufficient semantic processing of the items.

On the other hand, the presence of structural (including phonetic-articulatory processes) in 11 to 14-year-old children does not testify to their presence in 6 to 7-year-old children approaching the first phases of learning to read, in which the role of phonetic-articulatory competence can also be greater. In any event it was a little surprising not to find great differences between younger and older deaf children. Older children revealed only a slightly superior reading comprehension level and comparable error tendencies with a minor tendency to falsely recognize associated distractors.

Since we were forced to test almost all the deaf children at our disposal, there was not the possibility of a more accurate selection of subjects but—with respect to hearing deficits and other variables affecting school achievement—there were no evident differences between the two groups. Our results could indicate that differences in cognitive development and learning to read between 10-11 and 12-13 years are in deaf children very slight.

Hearing children made a larger number of errors with synonyms than with associations, but this trend—indicating accurate semantic coding—was not clearly present in deaf children. Rather, in the younger deaf group, an opposite trend appears which is not present in the older group. This is the only difference we observed in the two groups, but we cannot connect this difference to reading comprehension ability, which was extremely low in both groups.

The two different categories of structural distractors do not allow clear comparisons because of the difficulties of distinguishing between them in the Italian language. In any event we can observe a slightly greater tendency in deaf children, with respect to hearing groups, to rely on visual rather than phonetic properties. Nevertheless, this tendency does not deny the main result concerning the greater frequency of both kinds of structural errors in deaf subjects. It must also be observed that the visual errors, too, could be due either to phonetic or to articulatory confusion caused by the higher number of letters shared by basic and distractor words, the articulatory components having in this case probably a greater role than in phonetic, rhyming words. Further experimentation will try to distinguish between articulatory, phonetic, and visual errors, selecting words which are similar only either in the first group of letters or in the last group (and are rhyming) or share the general form and many non-consecutive letters.

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Surface Dyslexia and Its Relationship to Developmental Disorders of Reading

Jacqueline Masterson
Institute of Psychology
University of Padova, Italy

A comparison is made of characteristics of the reading and spelling of five adult neurological patients suffering from the reading disorder known as surface dyslexia, and four children suffering from reading disorder in the absence of any observable signs of neurological damage. The four main symptoms of surface dyslexia are: (1) greater difficulty in reading aloud irregularly-spelled words (such as *gauge, debt*) than regularly-spelled words (such as *grill, turn*), (2) errors in reading aloud characterised by regularizations and visual errors, (3) spelling errors are usually phonologically correct, (4) confusions between homophones in defining printed words. These symptoms were all found in the reading and spelling of the four children with reading disorder.

Since Marshall and Newcombe in 1973 drew attention to the fact that acquired dyslexics can be grouped together into syndromes such as deep and surface dyslexia on the basis of the types of error they make in reading, there have been a number of attempts in the literature on reading disorders in children to draw parallels between certain of these acquired dyslexic syndromes and childhood reading disorder. For example Jorm (1979) and Snowling (1980) suggest that the relative difficulty that developmental dyslexics have in reading aloud non-words parallels the difficulty that deep dyslexics have with this type of material.

However, there is only one study, as far as I can ascertain, which has consisted of making a direct comparison between the reading behaviour of acquired dyslexic patients and a group of children with developmental reading disorder. This was the study of Jane Holmes (1973) who gave over 800 words for reading aloud to each of four boys with developmental reading disorder and to two surface dyslexic patients. She analysed reading errors according to violations of rules of English spelling such as the rule that final silent *e* indicates that a preceding vowel should take its long form, or that the ambiguous consonants *g* and *c* are soft before *e*, *i*, and *y*, otherwise hard. She found that errors involving the violation of these rules could be observed for the developmental dyslexic boys as well as for the acquired surface dyslexic patients.

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Author's address: Institute of Psychology, University of Padova, Padova 35139, Italy.

The present investigations involved some new tests of surface dyslexia and the aim was to show that further characteristics of the disorder can be observed in children with developmental disorder of reading. The subjects of the investigations were five acquired surface dyslexic patients, four of whom had a reading disorder as a result of head injury, and one of whom had become dyslexic following a cerebrovascular accident, and four children suffering from reading disability in the absence of any observable signs of neurological abnormality. The four children were of average or average to bright intelligence and had adequate cultural and educational opportunity but were nevertheless reading at a level that was in excess of two years below their chronological age. Background information for all nine dyslexics is summarised in Table I.

Surface dyslexia can be diagnosed fairly easily by presenting the patient with a set of matched regular and irregular words for reading aloud and looking for a decrement in performance with the irregular set. Because the surface dyslexic is forced to rely on letter-sound, or grapheme-phoneme rules to read, due to the occasional inavailability of the direct route, irregular words will be read aloud incorrectly since, by definition, they form exceptions to these letter-sound rules. However, since the only means to read aloud that the surface dyslexic has is by means of letter-sound rules he will treat irregular words as if they were regular so that his errors to these will consist of regularisations, that is, of treating an irregular correspondence as if it were a common or regular one.

A matched set of regular and irregular words, randomly intermixed, was presented to the five acquired dyslexic patients and to the four developmental dyslexics for reading aloud and the results of this test are presented in Table II. The subjects all show a decrement in performance for irregular over regular words. The largest decrement in performance is shown for the developmental dyslexic K.W. Holmes (1973) has suggested that developmental dyslexics may develop a phonological reading strategy as a result of phonics-type remedial therapy that they may receive for their reading problem. K.W. had been receiving this type of therapy for the last two years so this may account for the large regularity effect that she shows. However, the other three developmental dyslexic subjects have not received remediation for their reading problem so this factor cannot be invoked to account for the regularity effect that they show.

Table III gives the results of two of Cochran's Q tests carried out on the errors of the acquired dyslexics to the regular and irregular sets of words. These revealed that there was agreement across subjects in the errors made to the irregular word set, but not to the regular word set. When the errors of the acquired and developmental dyslexics were compared for the irregular words, that is, when the number of subjects reading individual items incorrectly was compared across the two groups, it was found that there was a strong relationship between the words found difficult by the two groups of subjects, as the result of the Pearson's r test shows. In other words, the developmental dyslexics not only show a relative difficulty in reading aloud ir-

Table I. Background information for the five acquired and four developmental dyslexics.

Developmental dyslexics

		C.D.	F.E.	M.J.	K.W.
1.	Age	16 Yrs.	26 Yrs.	10:6 Yrs.	10:6 Yrs
2.	Sex	Female	Male	Male	Female
3.	Handedness	Right	Right	Right	Right
4.	Family left handedness?	Yes	Yes	Yes	Yes
5.	Family history of reading problems?	Yes	No	No	No
6.	Intelligence	Average	Verbal: average Non-verbal: superior	Bright average	Average
7.	Reading age	10:2	12:3	7:10	8:4

Acquired dyslexics

		A.B.	E.E.	C.H.	K.M.	P.M.
1.	Age	16	41	54	20	19
2.	Sex	Male	Male	Male	Female	Male
3.	Employment	Fitter	Postman	Author	Hairdresser	Mechanic
4.	Handedness prior to accident	Left	Left	Right	Right	Right
5.	Cause of accident	Road accident	Fall	CVA	Road accident	Road accident
6.	Site of Lesion	Right frontal area	Bilateral (right: temporoparietal area) lesion not specified)	Left (fronto-parietal area)	Bilateral (left: Bronca's cortical)	Brainstem lesion, bilateral pyramidal signs.

regular words, as do the acquired dyslexics, but they also give erroneous responses to the same items as the acquired dyslexics.

The difficulty with irregular words that acquired surface dyslexics have can also be shown in silent reading tests. The results of one such test are presented in Table IV. In this test the subject is required to judge whether pairs of printed words sound similar or whether they sound different. Three types of material are used: regular words, irregular words, and non-words, and there are fifty pairs of each type. It can be seen from the table that performance for the seven subjects for whom data is available is roughly equivalent for regular words and non-words and worst with irregular words. This pattern is what one would expect if the direct route for reading is sometimes unavailable since regular words and non-words can both be read by means of grapheme-phoneme rules whereas irregular words cannot. The performance of adult normal readers appears under that of the seven subjects.

Table II. Results for nine subjects reading aloud regular and irregular words (39 of each). Results are expressed in terms of percent correct.

Acquired dyslexics						
AB	EE	CH	KM	PM	X	
Regular	69	56	72	64	54	63
Irregular	51	26	46	51	33	41
Developmental dyslexics						
	CD	FE	MJ	KW	X	
Regular	90	79	59	77	76	
Irregular	67	38	46	28	45	

Table III. Incorrect responses to regular and irregular words made by acquired dyslexics

	Regular	Irregular
Cochran's Q	4.23 ($p > .05$)	9.85 ($p > .05$)
Incorrect responses to irregular words made by acquired and developmental dyslexics.		
Pearson's R		0.67 ($P > .001$)

Table IV. Results for nine subjects on silent tests of phonology in terms of percent correct.

Acquired dyslexics						
	AB	EE	CH	KM	PM	X
Regular	78	74	—	68	74	73
Non-words	76	70	—	70	65	70
Irregular	60	52	—	54	56	55
Developmental dyslexics						
	CD	FE	MJ	KW	X	
Regular	88	—	78	72	79	
Non-words	78	—	74	72	75	
Irregular	68	—	62	58	63	
Mean adult performance on silent tests of phonology (N = 13)						
Regular	99					
Non-words	96					
Irregular	97					
Mean performance of children with reading age = 10.00 years on silent tests of phonology (N = 18)						
Regular	95					
Non-words	89					
Irregular	89					

We have also found that normal beginning readers experience the same difficulty in reading irregular words that is demonstrated by acquired surface dyslexics. However, this difficulty does not persist into adolescence for normal readers as it has for the four developmental dyslexics who are reported here. If we compare the performance of one of the developmental dyslexics, C.D., on the silent tests of phonology with that of children matched for reading age, whose results are at the bottom of the table, we can see that her difficulty with irregular words is not just due to the fact that she has a depressed reading age. That is, despite the fact that she has only a reading age of 10 years when her chronological age is 16 years, she should not, having achieved this reading age, still show a regularity effect in her reading. Given that she does show such an effect when her reading-age matched controls do not, we must conclude that it is a consequence of her reading difficulty rather than a natural consequence of having such a depressed reading age.

Table V shows that the difficulty with irregular words relative to regular and non-words is not a feature of the reading of all developmental dyslexics and indeed seems

Table V. Results for 21 developmental dyslexics on silent tests of phonology (per cent correct).

Children showing a decrement in performance for non-words

	Regular	Non-word	Irregular	
S1	84	54	64	
S2	84	74	82	
S3	100	84	96	
S4	62	50	68	
S5	94	78	86	
S6	72	54	68	
S7	84	62	74	
X	83	65	77	

Children showing a decrement in performance for irregular words

	Regular	Non-word	Irregular	
S1	92	92	80	
S2	88	84	68	
S3	66	64	44	
S4	80	84	66	
X	81	81	64	

Children showing neither pattern

	Regular	Non-word	Irregular	
X	83	83	80	(N = 10)

to be a feature of only a minority of them, since 7 of the 21 developmental dyslexics in this sample showed a greater degree of difficulty with non-words than with irregular words compared to regular words. These children were all untreated developmental dyslexics, between the ages of 12 and 18 (Masterson, 1982, unpublished experiment).

Turning now to a qualitative, rather than a quantitative comparison of the errors of the nine subjects, it was mentioned earlier that irregular words should produce regularization errors when they are read aloud by the surface dyslexic because he is relying on grapheme-phoneme rules to read them. This type of error was observed for the five adult surface dyslexics and also for the four developmental dyslexics. Examples of regularization errors are to be found in Table VI. Visual errors are also observed in the reading of all acquired surface dyslexics (for examples, see Table VI), and these also occurred in the reading errors of the four children.

Two judges, trained in phonetic transcription, were given the individual error corpora for all nine subjects to the regular and irregular words and were asked to judge whether each set of errors had been made by an acquired or a developmental dyslexic. From Table VII it can be seen that although the judges were mostly correct in their judgements about the developmental dyslexics, they also thought that the errors of the five acquired dyslexics had been made by developmental dyslexics, indicating that the errors of the two types of subject in this study cannot be reliably differentiated.

The spelling errors of the five acquired dyslexics in the sample were found to be mostly phonologically correct (see Table VI for examples), and this was found to be true also for the developmental dyslexics.

Acquired surface dyslexia can be diagnosed by a fourth symptom: that of homophone confusions. Since reading is mediated by phonological recoding in this type of reading disorder, the patient will be unable to differentiate, in terms of meaning, between printed words which, although spelt differently, sound the same. When the patients were presented with printed homophones for which they had to provide spoken definitions before reading them aloud, they made homophone confusion errors, examples of which are to be found in Table VI. It can be seen from this table that the errors involved providing a definition appropriate for the target's homophone. When the same test was administered to the developmental dyslexics they also made these errors. Thus, all of the characteristics of acquired surface dyslexia—a regularity effect in reading aloud, regularizations and visual errors, phonologically correct mis-spellings, and homophone confusions—were observed for the four developmental dyslexic subjects in this study (see Masterson, 1983, for a full comparison of the data for the nine subjects).

It is tempting to speculate that the type of reading disorder exhibited by the four developmental dyslexics described here is the same as that shown by the children in Eleanor Boder's category of developmental dyslexia which she calls dyseidetic dyslexia and which she says is the same as the subtype of visual dyslexia described by other authors who have conducted subgrouping studies of developmental dyslexia. Boder (1971, 1973) describes dyseidetic dyslexia as involving reading through a process of phonetic analysis of printed words and also a phonological spelling strategy. She found that dyseidetic dyslexics formed only 9 per cent of the sample of 107 developmental dyslexics that she tested.

However, the reading and spelling errors made by the dyseidetic dyslexics in Boder's study, and by children in subgroups of other studies, have not been described in sufficient enough detail for us to conclude that any of these subgroups correspond to the form of reading disorder described here.

This highlights the need for the detailed recording of data from individual subjects in investigations of developmental dyslexia in order that the strides forward that

Table VI. Examples of different types of error in reading and spelling made by the five acquired and four developmental dyslexic subjects.

Regularization errors in reading aloud irregularly-spelled words
e.g., bury—/bxri/, sword—/swxd/, mortgage—/mxtgeidx/, subtle—/sxbtal/

Visual errors in reading aloud
e.g., gang— gag, check— cheek, bowl— blow, quick— quack

Phonologically correct spelling errors
e.g., search— SURCH, cough— COF, concert— CONSERT, safety? SAIFTY

Homophone confusions in defining printed words
e.g., pain— "a piece of glass in a window", blew— "a colour", brake— "to smash", seas— "to grab someone"

Table VII. Judgements about whether errors were made by a developmental or by an acquired dyslexic.

		Judge 1	Judge 2
Acquired	AB	Developmental	Developmental
	EE	Acquired	?
	CH	Developmental	Developmental
	KM	Developmental	Developmental
	PM	Developmental	Developmental
Developmental	CD	Developmental	Developmental
	FE	Acquired	?
	MJ	Developmental	Developmental
	KW	Developmental	Developmental

have been made in studies of acquired dyslexia can also be made for investigations of developmental disorders of reading.

In conclusion, all of the features of acquired surface dyslexia observed for the five adult neurological patients were also observed in the four developmental dyslexics in the present study. A number of investigators have expressed the view that the reading characteristics of acquired and developmental dyslexics are unlikely to be similar. For example, Masland (1981) writes of acquired and developmental dyslexia that "the disorders of function which result from the destruction of an already established structure must be very different from those which occur when functions are developed within a structure which has been abnormal or damaged throughout the developmental period". The investigations presented here indicate that both types of disorder can have identical consequences for reading behavour.

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Reading and Remembering: A Constructivist Perspective on Reading Comprehension and Its Disorders

Camille L. Z. Blachowicz
National College of Education
Evanston, Illinois

This paper reviews several models of reading which have influenced educational practice and presents a schema-theoretic perspective on reading comprehension. Such a framework proves fruitful for investigating young readers' knowledge of and use of prose structure and offers a model within which to reconsider disorders of comprehension. The concluding section looks at the instructional research on schema availability and maintenance as well as work on children's comprehension and metacomprehension and suggests further research on the cognitive components of reading difficulty.

The history of research and pedagogy in reading reflects growth and change in the social sciences. In the last decade the number of models, theories, and hypotheses explaining how people learn to read, read to learn, and remember from reading has rapidly expanded (Singer and Ruddell, 1976; Wolf, McQuillan, and Radwin, 1980). Along with theoretical shifts, changes in reading research and pedagogy have emerged from the fertile cross-pollination of work in linguistics, psychology, and pedagogy.

This paper will focus on examining the ways in which theoretical changes in conceptualizing memory and language comprehension are affecting reading research as well as the teaching and assessment of reading and perspectives on disorders of reading comprehension.

Views on Memory and Models of Reading

Models of memory have always been relavant to reading educators; conversely, reading has been a frequent topic of study for psychologists looking for another window into the mind.

Two distinct theories that have emerged from efforts of psychologists to account for the remembering process have been especially seminal for educators. The first has been called the "reappearance" or abstract trace hypothesis (Neisser, 1966). Central to this position is the notion that remembering involves reviving a memory

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Author's address: National College of Education, 2834 Sheridan Road, Evanston, IL 60201.

trace which essentially is a stored copy of the sensory experience. The content of the trace can be completely described by the initial event and, thus, remembering involves locating this trace in memory and bringing its contents to consciousness.

This viewpoint is consistent with learning theories that characterize the human organism as being driven by sensory stimuli which are said to "evoke" or even "control" responses. Seen in this light, higher order processes are amalgamations of simple, lower order processes. This logical empiricism, so typical of much of the input from the social sciences to American education, has predominated both philosophically and methodologically in the preceeding two decades.

Early models of reading flowing from this influence, such as that proposed by Gough (1972), contend that processing in reading is data-driven in that all decisions about visual units, such as letters or words, must be made before the data are transformed into the kind of meaning code necessary to allow instantiation into long term semantic memory. The memorial structures never serve to direct the hypotheses about what a particular word or letter might be.

When reading is analyzed in this way, the component levels of processing appear to be organized hierarchically and the attainment of any given level presumes the execution of all subordinate levels. Further, the motion is conceived of as being unidirectional. Whereas the reading of the text depends on the reading of its sentences, words, and letters, an individual letter may be perfectly legible whether or not it is embedded in a word of larger context. Similarly, readers are able to read individual words, phrases and sentences in the absence of a larger context.

The appeal of this analysis of reading is in its logical simplicity. For pedagogues it provides a rational structure for instructional programs starting with the letter, or perhaps lower with the features of letters, and working up to larger contexts. For researchers it provides a method of isolating and organizing processes.

The difficulty with this approach is in its ecological validity. When one is reading a meaningful, contextually rich passage, the normal reading activity, one does not seem to focus on letters, words, and phrases in the same way as one does in an out-of-context experimental situation. Rather, processing at each level is influenced by both higher and lower order information. Thus, individual letters become more easily perceived when embedded in words (Wheeler, 1970; Kolers and Katzman, 1966), individual words are recognized more easily when embedded in meaningful sentences (Kolers, 1970; Tulving and Gold, 1963), the perception of unfamiliar words is enhanced by a familiar context (Wittrock, Marks, and Doctorow, 1975) and sentences that integrate conceptual relations are more easily read even if their syntactic complexity is greater (Pearson, 1974-75; Haviland and Clark, 1974).

These sorts of facilitations from context greatly ease the task of reading but complicate the business of research. They challenge the empirical, bottom-up models of reading and bring into question instructional practices based on logical analyses of reading.

A second theory of remembering, commonly referred to as "constructive" theory

(Bransford, Barclay, and Franks, 1972; Anderson and Ortony, 1975) also involves the notion that remembering requires finding and bringing to consciousness stored records of past events. However, in this case, the contents of memory are not definable in terms of the initial experiences that created the traces. Rather, the contents of the memory trace are jointly determined by the initial event, the present knowledge structure of the learner and the salient features of the environmental context in which the event takes place. Whereas reappearance theory would suggest that memory of identical sensory experiences should be the same for two learners (with the exception of omissions of content), constructive theory would suggest that two learners experiencing the same event would very likely have very different contents in their memory representation.

Emerging from this conceptualization of memory has been the proposal of an essentially top-down model (Goodman, 1976; Smith, 1978) with a conceptually driven processing model. In these models bottom-up processing is necessary only in the most dire of contextually impoverished circumstances, such as the paired associate tasks of experimental research design.

To a certain degree such simplistic models as a strict top-down or bottom-up model are no longer being proposed to account for the process of skilled reading, nor is need for efficient bottom-up processing seen as contradictory to a model which looks at the contribution of context at all levels (Stanovich, 1980; Samuels and LaBerge, 1983). However, investigations of pedagogical practices and instructional materials reveal that these oversimplified constructs well reflect the dichotomy that exists between the two major approaches to beginning reading and are also representative of the literature of teacher training (Smith, 1982; Downing, 1977).

Still other models, most notably that of Rumelhart (1977), argue for a constant and simultaneous generation of hypotheses about both visual and meaningful information. The domination of one mode (data-driven versus conceptually driven) over another depends upon factors such as background knowledge, text difficulty and the nature of the reading task. Interactive models describe reading as a constantly shifting interactive process depending on familiarity with the topic, the syntax, the lexicon, and purpose for readings; for example, understanding versus proofreading.

Such interactive models are particularly attractive to reading educators because they better explain collected data on reading performance. Extensive observational data collection on reading performance suggests that syntactic and semantic variables influence the reading behavior of even very young readers (Biemiller, 1970; Weber, 1970).

It is Rumelhart's type of interactive model which is now a dominant one shaping pedagogical practices and research in reading. Central to this model, the constructive view of memory undergirding it and the processes it engenders is the theoretical construct "schema." Though recently emphasized, it is a concept in early psychology (Bartlett, 1932; Head, 1926; Woodworth, 1938) and finds even earlier amplification in philosophy and formulation of rules of "productive imagination" (Kant, 1787). A simple discussion of the term will set the stage for understanding the emerging trends in research and practice.

What Is a Schema?

A schema is an hypothetical knowledge structure which represents an organization of a comprehender's experiences with the real world. The term hypothetical is important as a caveat against reifying a structure that we can only hypothesize on the basis of observation and experimentation. These knowledge structures are abstract in that they are not merely an accretion of experiences but rather a generalization from experiences.

The term schema applies to a wide range of objects, ideas, and phenomena. For example, one might have a schema for *chair*, for *fidelity*, and for actions such as *buy*. Schemata have been characterized as not corresponding to one particular experience but rather to a common set of features, for example, those features of chair that make recognizing the next one possible. Alternatively, the schema may not be so much a set of abstract features as a prototype, as, in the case of chair a dining table chair (Rosch, Mervis, Gray, Johnson, and Boyes-Braem, 1976). Besides objects, one can consider schemata for ideas, such as *fidelity*, for actions such as *buy, sell, give,* and for events, such as attending a conference, giving a paper, and so forth.

Rumelhart (1977) has compared schemata to plays. Just as a play has a plot, characters and actors, so schemata have corresponding parts. For example, in a *buy* schema, there is a buyer, a seller, an object to be purchased, a money, a place for exchange. These are the cast and setting of a play. In such a schema, there is an order to the process, much like the order of scenes in a play. Last, there are the actors, the particular buyer, seller, object, and so forth.

One important characteristic of schemata is their hierarchical organization. For example, the schema for attending a soccer game is seen as embedded in the more general framework of attending a sporting event which is, in turn, embedded in a larger schema for attending large social events (Rumelhart and Ortony, 1977). A great deal of research has been done to verify that semantic networks of relations among various concepts or schemata exist (Shoben, 1980). A hypothesized cross-referencing occurs when variables in one schema are filled by values that exist within other schemata and the explanation of this crossover is a prime consideration of work in artificial intelligence (Minsky, 1975; Winograd, 1975).

Whether conceptualized as scripts, plans (Schank and Abelson, 1975), frames (Minsky, 1975) or schemata, another essential component of this type of knowledge structure is that of variable slots which can be likened to the roles in a play. These slots are filled (instantiated) by values which can be different or changing. For example, in a *buy* schema, any human being is a potential for filling the slot of buyer. For a medium of exchange, fewer values exist; for example, cash, check, or credit card.

Variable constraints exist in the situations which supply the boundaries for the range of things that can fill a particular slot. For example, in a *buy* schema, consider the purchase of a small scarf. There, the variable constraints on payment would allow for any of the alternatives mentioned. If the object to be purchased is a house or apartment, the cash payment becomes extremely unlikely.

This facet of schema structure has been most interesting to reading educators in that it allows for enrichment of the text through elaboration and inferences. While inference on a larger scale is involved in the process of deciding which schema among many can be called into focus, it is also involved in the process of instantiating variable slots within a selected schema. This can occur in different ways. First, one may use inferential processes to decide that a particular value mentioned in a story is intended to fill a particular variable slot. For example, "I went out to buy shoes yesterday. My, was Field's crowded." In this case, one might infer that the shoes were purchased at a store called "Field's" even though that was not explicitly stated in the passage. The reader makes a text-connecting inference, recognizing the relationship between the elements of two different text segments.

A second way in which inferences function is by the assignment of default variables to variable slots in the absence of any information from the text. A default value is simply the comprehender's best estimate of what is likely to fill a particular slot. This choice is constrained by the comprehender's knowledge of the variable constraints for a particular slot. For example, for "I ate all the soup. It was delicious," one will most likely infer *spoon* rather than *knife* as the instrument used to manage the deed of eating the soup. A large body of evidence suggests that we quite normally make routine inferences of objects, instruments, and spatial and logical relations when we read and listen (Bransford and McCarrell, 1974). This drawing of prior knowledge to "fill in" information from text and the metacognitive awareness and strategies necessary to do so are significant areas of investigation in current reading research and in the development of instructional methodologies for enhancing comprehension.

Current Research and Practice

In looking at reading one can see that there are different types of schemata that come into play in the process of skilled reading. Readers can have schemata for particular types of content, for certain types of communicative structures and for the kinds of processes governing differing approaches to print. Researchers and practitioners are looking at prior knowledge related to specific content and at the inferencing processes made possible by such background knowledge. Also under investigation are young readers' knowledge and use of prose structure to facilitate comprehension and learning. Further, schema theory offers an excellent model within which to reconsider disorders of reading comprehension.

Perspectives on Disorders of Comprehension

An historical examination of the research of reading disability will reveal many attempts to isolate the factors of memory and perception as the primary variables which distinguish good from poor readers. Many investigations suggested that disabled readers exhibit deficits on retention tasks (Alwith, 1963; Senf, 1973; Noelker and Schumsky, 1973; Samuels and Anderson, 1973).

When reviewed, however, the research on memorial processes of disabled readers has been equivocal at best. The bulk of the research normally cited utilized non-meaningful stimuli which make extrapolation to reading comprehension difficult. Indeed, the supposition of generalized poor memory processes as an explanation for reading disability is now in question (Torgesen, 1978-79, gives an excellent review). Clinical researchers are looking for more specific differences in processing and are finding some insights from developmental research on schema utilization and enhancement.

Three characteristics of schematic processes which are obviously related to reading performance are schema availability, schema activation, and schema maintenance. In terms of instructional analyses this necessitates looking at the prior knowledge readers bring to a reading act, their awareness of prose structures and their ability to recognize and control processes needed to approach, assimilate and use the content and structure for purposes appropriate to their reading tasks.

The Role of Prior Knowledge

Looking at prior knowledge, Omanson, Warren, and Trabasso (1978) find it a powerful variable that has often been a confounding one in analyses of difficulties of comprehension. Working with five-year-old and eight-year-old subjects who had equivalent levels of veridical recall, they found that the eight-year-olds drew significantly more inferences than the younger subjects. Since inferential limits were not due to memory capacity, it was hypothesized that they were consequences of insufficient prior knowledge. In other words, their background knowledge was insufficient to extend the literal for inferential comprehension.

Working in the same area, Pearson, Hansen, and Gordon (1979) focused on young readers whose abilities to answer literal questions after reading were equivalent. Those with greater prior knowledge on the topic, in this case knowledge about spiders, performed better on all inferential tasks, supporting the conclusions of the former study. Similar results were found by Marr and Gormley (1982) and Hayes and Tierney (1982) who analyzed variations in reading thought to be due to general reading ability; the main part of the variance in performance could be attributed to differences in prior knowledge about the topic.

The process of maintaining the appropriate schema or changing to another when it is called for is another area of processing which can cause difficulty in reading. Research suggests that poorer readers have more difficulty in recalling connections across sentences (Spiro, Boggs, and Brummer, 1979) and in connecting information in sentences which are not contingent (Di Vesta, Hayward, and Orlando, 1979). In general, it appears that relationships between ideas in separate sentences unlinked by cue words (such as *because, since, therefore*) are more difficult for disabled readers to comprehend than more explicitly linked text (Marshall and Glock, 1978-79; Irwin, 1980). In working with disabled older readers with a visualizable text, Blachowicz (1979; 1980) found that their literal comprehension performance was equivalent to their IQ-matched age mates. However, their performance differed significantly on tasks involving drawing connections between two and three sentences.

Instructional programs aimed at dealing with these difficulties have historically attended to schema activation as the long history of work on advance organizers demonstrates. The many reviews of this work (Barnes and Clawson, 1975; Mayer, 1979) reflect a confused picture where the effect of the organizer is extraordinarily sensitive to constraints of age, ability, textual, and presentational factors.

Current work has focused on the means of creating prior knowledge in a reading context. Building such knowledge with analogical text has produced greater comprehension of new material (Royer and Cable, 1976; Mayer, 1975; Hayes and Tierney, 1982). Similarly, reading a first selection about a topic facilitates the comprehension of a second selection on the same topic (Crafton, 1980).

Presentation of vocabulary has received much lip-service in instructional materials manuals as a knowledge building technique, but guidelines for such presentation have been noticeably scanty (Beck, McKeown, McCaslin, and Burkes, 1979). However, though the relationship between vocabulary knowledge and reading comprehension performance is well established (Davis, 1944; 1968) instructional intervention designed to improve comprehension through the presentation of vocabulary has been relatively ineffective (Meyzinski, 1983). A few recent studies emphasizing the teaching of terms in relational sets with students actively relating new words to known, have demonstrated some influence on comprehension of text containing those words (Draper and Moeller, 1971; Swaby, 1977; Johnston, 1981; Beck, Perfetti, and McKeown, 1982). Currently several studies are underway attempting to tease out the ways in which successful teachers present new terminology and help students to relate these new words to existing vocabulary and concepts (Beck, 1983; Blachowicz, 1984).

Metacognition

Spiro (1975) proposes that the problem need not only be one of schema availability, having the appropriate prior knowledge, but may also be conceptualized as a difficulty in schema activation and integration. He suggests that many readers approach reading tasks as if they were memory experiments rather than as opportunities for expanding knowledge. Subjects in several of his experiments were presented with information in a read format that was modified by later new input. He found that they appeared to compartmentalize new information gained in the reading tasks as separate from prior "real life" knowledge. He suggests that there may be differing styles of processing relating to reading with some readers regarding the text base as separable from and non-assimilatable into one's knowledge base. Spiro alternately suggests that information gained from reading is not seen as very "real" or important and, thus, is not integrated into the general knowledge base.

This type of difficulty with reading can also be characterized as one of metacognitive strategies. Brown and Smiley (1978) have found that young children often do not know the important units of information in discourse. Children who do spontaneously attend to the important units in the text, who underlined, took notes and so forth, have improved comprehension. Several other studies suggest that young children often do not know the semantic structures of the text, strategies for comprehending meaning or objectives for reading a text (Mayer and Paris, 1978).

In terms of pedagogical research, then, a primary thrust is to develop research-verified techniques for enhancing comprehension behavior and for developing the inferential strategies of poor readers. Comprehension can be considered a "generative" process in that the reader's active construction of verbal, imaginal, and related representations of the text produces or enhances the understandings that comprise reading comprehension. It is interesting that an emerging body of research showing growth in inferential processes involves having readers act, as it were, on the text, producing an enhanced comprehension. This process of construction can take many forms. Hansen (1981) carried out a study with school age children in which the experimental treatment involved generating predictions about events in the material to be read and answering questions which involved constructing inferences between the text and prior knowledge. Both treatments resulted in significant growth in comprehension on both standardized and experimenter-constructed measures.

Doctorow, Wittrock, and Marks (1975) asked young readers of high, average, and low ability to summarize each paragraph they read in a sentence immediately after reading it. Some of the groups of students also received paragraph headings as aids to serve as cues for the relevant schema. The sentence generation task was hypothesized to facilitate the construction of relations between the reader's schemata and the story. As was predicted the generation of sentences and presence of cues enhanced retention and comprehension, with the combination of the two doubling comprehension at each level of ability.

Such elaborative processes may be especially important for readers whose culture differs from that depicted in materials to be read. Au (1977) reported results of a cognitive training program used to enhance comprehension of minority Hawaiian-American students. This program emphasized the action of verbalization of their experiences and knowledge as they read stores. The teacher's questioning emphasized translation activities, recall of personal events that related to the story and the drawing of inferences. Again, the program was marked by significant gains for the experimental subjects over control groups as well as by changes in attitude toward reading.

Paris, Lindauer, and Cox (1977) taught children to construct paragraphs about sentences they read which would integrate the sentences into a meaningful whole. The children were able to construct inferences relating the sentences but it was not a spontaneous process. Thus, though not deficient in the ability to produce inferences, they did not seem to have the control strategies to call up such processes on their own.

In a study with related conclusions, Bommarito and Meichenbaum (1978) taught reading disabled children in the junior high school to organize their reading habits as they read a story. They asked themselves questions about main ideas, important details, sequence of events and characters, feelings and responses. The training group again showed significant gains in comprehension and suggested that this lack of spontaneous inferencing behavior is characteristic of both young readers and of poor readers.

Armbruster (1979) has utilized a text-mapping strategy to help students learn from expository text. Following reading, students construct a visual display of the relations emphasized in the text. Such mapping makes the key ideas explicit and enhances learning from the text. Raphael and her associates (1980; 1981; 1982) has carried out a number of studies to teach young readers to differentiate among levels of questions they are asked and the appropriate search strategies for answering them. Looking for literal information (Right There), inferential information (Think and Search) or schema based answers (On My Own) sensitizes students to types of reading and reasoning necessary for effective reading.

Palincar and Brown (1983) developed an instructional cycle of self-monitoring for learning disabled adolescents. The process involved summarizing what was read, generating questions, predicting what would be coming in the text and clarifying unclear passages. The format was that of "reciprocal questioning" with the students and the teacher alternating in the teacher role. In this way the teacher both provided a model and feedback for the less effective readers. The reciprocal questioning cycle proved effective in enhancing the students' learning from expository text.

Conclusion

Viewing the area of reading education research, one comes away with several impressions uniting what seems to be a wide ranging body of research. Most obvious is that the debt of the field to psychology, linguistics, and sociology continues to be great. The river of reading education is contained within the banks of the social sciences and reflects the movement away from a conceptualization of memory and comprehension as stimulus-response activity towards one stressing constructive processes on the part of the comprehender. Conceptualization of and research in memory has had especially direct and analogical influence on work in reading.

The stuff of comprehension is clearly not viewed as residing on the pages of text. Rather, reading comprehension occurs only when readers use their psychological processes, perception, attention, encoding, and memory to transform the printed symbols into meanings reflective of their knowledge and experience. These processes, along with the linguistic, neurological, and pragmatic variables influence the meanings readers construct as they move through a text. The outcome of reading, therefore, consists of more than a reconstruction of the author's meaning. Rather, within the constraints of the lexicon and syntax, readers construct one or more messages consistent with their knowledge structures and those they perceive to reflect that of the author.

This viewpoint is of special interest to those interested in disorders of reading because it provides a new perspective from which to view breakdowns of the reading process. Lack of appropriate schemata, undeveloped control strategies for maintaining or varying schemata can all be associated with failures to comprehend.

There appear to be some developmental trends in the ability of a reader to control strategies for making inferences so necessary to higher order comprehension. These processes, even when not spontaneous, seem to be able to be induced, further challenging the generalized memory deficit view of reading disability. Individual differences in the ability to generate appropriate elaborations seem to exist and the research is emerging to indicate ways to enhance comprehension strategies. Thus, along with considerations of attention and neurological functioning, the construction of a knowledge base and ways to enhance its utilization and control should prove to be prime considerations in reading education research for years to come.

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The Authors

Dominic W. Massaro has been professor of psychology at the University of California, Santa Cruz (Santa Cruz, CA 95064) since 1980. He has received research fellowship awards from both the National Institutes of Mental Health and the Guggenheim Foundation. His research interests are human information processing, speech perception, and reading. Among his publications are *Experimental Psychology and Information Processing* (Rand McNally, 1975), *Understanding Language* (Academic Press, 1975), and *Letter and Word Perception* (North Holland, 1980).

Cesare Cornoldi is professor of general psychology at the Istituto di Psicologia at the University of Padova (35100 Padova, Italy). For four years he was national delegate of the Experimental Psychology Division of Italy, and has published in numerious Italian journals. Dr. Cornoldi's research explores learning and memory problems both in normal and disordered subjects.

Alan Baddeley has been director of the Medical Research Council Applied Psychology Unit (Cambridge CB2 2EF, England) since 1974. His particular interest is in working memory, the role of temporary storage in information processing. Dr. Baddeley's publications include *The Psychology of Memory* (Basic Books, 1976) and an introduction to memory, *Your Memory: A User's Guide* (Macmillan, 1982). *Working Memory* is shortly to be published by Oxford University Press.

Francesca Simion is associate professor in the Department of Developmental and Social Psychology at the University of Padova (35100 Padova, Italy). Her particular interest is conceptual and linguistic development and the neuropsychological correlates of the human information processing approach. Currently she is studying the relationship between conceptual development and the generalization of names in the first years of life. She has also published on the basic processes underlying pattern recognition.

Beatrice Benelli is associate professor in the Department of Developmental and Social Psychology at the University of Padova. Her main research field is language acquisition and categorization processes. Her particular interest is the relationship between social and cognitive development.

Franca Tarantini is a recent graduate in psychology from the University of Padova. Her research work there concentrates on sensory-motor development and mother-infant interaction.

Cristina Burani is a research psychologist at the Istituto di Psicologia of the Consiglio Nazionale delle Ricerche (00157 Roma, Italy). She is interested in lexical processing in both normal and aphasics and is currently engaged in research on morphology and disorders of reading and writing.

Dario Salmaso is also research psychologist at C.N.R.'s Psychology Institute. He works in the area of neuropsychology with particular attention to processing of visual material, both linguistic and non-linguistic.

Alfonso Caramazza is professor of psychology at The Johns Hopkins University (Baltimore, MD 21218) where he has been since 1976. Dr. Caramazza's research is in the area of psycholinguistics, focusing on the contribution of language disorders in brain-damaged patients for the development of theories of normal language processing.

Giovanni B. Flores d'Arcais is professor of experimental psychology at the University of Leiden (Psychologische Functieleer, Hooigracht 15, Leiden, The Netherlands); he holds a joint appointment as research associate at the Max Planck Institut fuer Psycholinguistik in Nijmegen. He has been a research fellow at the Center for Cognitive Studies at Harvard and a Humboldt Scholar at the University of Heidelberg. His main present research interests are psycholinguistics and cognitive processes in general. He has written four books, edited three collections of psycholinguistic papers, and has published some fifty papers and book chapters in the areas of perception, cognition, and psycholinguistics.

Adele Cavedon is a research associate at the University of Padova (35100 Padova, Italy). Her particular research interests are color perception and memory.

Rossana DeBeni is also a research associate at the University of Padova and is particularly involved in the study of mnemonics and other aspects of memory.

Jacqueline Masterson is doing research at the Istituto di Psicologia at the University of Padova (35100 Padova, Italy). She is studying comparative aspects of reading and writing in English and Italian subjects on a grant from the Royal Society of England.

Camille L. Z. Blachowicz is associate director of the program in reading and language at the National College of Education (Evanston, IL 60201). She has worked as a reading educator in settings ranging from the classroom to federally funded projects. Dr. Blachowicz's current research deals with vocabulary learning and instruction, and she teaches graduate courses on this topic and those related to diagnosis and remediation of reading difficulties. Her work has appeared in such journals as *Reading Research Quarterly*, *Reading Psychology*, and *The Reading Teacher*.

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