THE DEVELOPMENT OF WRITTEN WORD PROCESSING: THE CASE OF DEAF CHILDREN[1]

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Reading is a highly complex, flexible and sophisticated cognitive activity, and word recognition constitutes only a small and limited part of the whole process. It seems however that for various reasons, word recognition is worth studying separately from other components. Considering that writing systems are secondary codes representing the language, word recognition mechanisms may appear as an interface between printed material and general language capabilities, and thus, specific difficulties in reading and spelling acquisition should be located at the level of isolated word identification (see e. g. Crowder, 1982 for discussion). Moreover, it appears that a prominent characteristic of poor readers is their lack of efficiency in the processing of isolated words (Mitchell,1982; Stanovich, 1982). And finally, word recognition seems to be a more automatic and less controlled component of the whole reading process.

In this paper, we shall compare the development of written word processing in normal and hearing disabled children. One pervasive debate in reading research concerns the role of phonological information in written word recognition, and deaf people's reading capabilities have often served as an argument in this controversy. We argue here that the way deaf children

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learn to read and spell actually supports the hypothesis that phonological information plays an important role in reading acquisition.

1. Word Recognition in Skilled Readers

The recognition of alphabetically written words is usually conceived as a two component system. One sub-system, generally called the **direct** or **orthographic** procedure, consists in matching written words with orthographic representations stored in the mental lexicon and associated with semantic, syntactic and phonological information (the phonological form obtained by lexical lookup is sometimes called **addressed** phonology). The other component, called **indirect** or **phonological**, is assumed to build a phonological code on the basis of the regularities linking letters and groups of letters and speech sounds. The **assembled** phonological form may then be used to access the lexicon as if it resulted from an auditory input.

The two functional components are sensitive to different variables. The orthographic route allows for direct recognition of familiar words but it cannot directly handle unfamiliar words or pseudowords (i.e. letter strings compatible with the orthographic regularities in the language, although not being words). The assembly procedure provides a phonological form for any letter string but, since it is based on the regular or on the most frequent grapho-phonological correspondences, the obtained phonology should necessarily be inadequate for any written word the pronunciation of which diverges from the norm (such as HAVE or PINT, irregular, vs WAVE or MINT).

It is generally assumed that the two processes run simultaneously and that the subject's overt behaviour for a given stimulus is determined by the fastest process. Most researchers consider that for skilled readers word recognition is mainly based on the orthographic procedure, the indirect procedure remaining available as a back-up mechanism for new and infrequent words. Evidence for this view can be borrowed in particular from studies of oral reading. For instance, several studies showed that words containing irregular grapho-phonological correspondences give rise to slightly longer naming times than regular control words (see i. e. Carr and Pollatsek, 1985 for a detailed review). More recently, Seidenberg and his collaborators (Seidenberg, Waters, Barnes and Tanenhaus, 1984; Waters, Seidenberg and Bruck, 1984) reported that the effect of regularity is restricted to low frequency words. Low frequency words involving exceptional spelling-to-sound correspondences require more time than regular ones, while no similar effect appeared in English for high frequency words. This pattern suggests that high frequency words are recognized by direct access, which is not sensitive to grapho-phonological regularity, and that the assembly procedure intervenes only in the recognition of low frequency words.

Most if not all models include some form of distinction between assembled and addressed phonology, but there is currently no agreement on the mechanism of the assembly process and its degree of independency from the lexical system. Early models (e.g. Coltheart, 1978) postulated that the assembly procedure functions on the basis of univocal grapheme-phoneme correspondence rules, stored independently of the lexicon. This view has been invalidated by empirical evidence showing that word and pseudoword pronunciation is affected by lexical factors, such as the existence of an orthographically similar irregular word (Glushko, 1979; see also Kay & Marcel, 1981; Campbell and Besner, 1981; Rosson, 1983; 1985 for various demonstrations of lexical influence on the pronunciation of pseudo-words). These and other studies have led several authors to propose alternative models in which the assembled phonology is obtained (or influenced) by the activation of words orthographically similar to the stimulus (cf. Henderson, 1982, 1985; Humphreys and Evett, 1985). For the time being, however, the evidence is not decisive: recent two-channel models explain a great deal of evidence for lexical contribution to the assembly process by postulating larger correspondence units (such as - VC endings, -EAK, -EAN, -EAD for example) and possibly multiple correspondences between one grapheme and several phonemes (Coltheart, 1985; Patterson & Morton, 1985).

In any case, most activation and synthesis models share the assumption that there must be some form of representation of sublexical or submorphemic correspondences in the system, thus admitting the existence of two distinct sources of knowledge. Whether the knowledge determining assembling is stored within the lexical system or not, and whether the assembling can best be described as an algorithmic or as an activation process are secondary questions from our point of view. For what concerns developmental issues, examining the developmental course of the acquisition of these two knowledge sources and their interactions seems a good starting point.

The two procedures just described also suggest a possible model for spelling. To spell a word, subjects may retrieve orthographic information stored in the lexicon (the addressing strategy), starting either from semantic information or from phonological input; when the orthographic representation is not available, subjects may apply sound-to-spelling rules (the assembling strategy). The lexical procedure can be used to spell familiar words but not pseudo-words, while the assembling procedure may be useful to spell pseudowords and regular words but not irregular words (see Morton, 1980; Ellis, 1984).

The functional independence of the assembling procedure from the lexical system has also been discussed in the context of models of words spelling. There is some evidence (Campbell 1983, 1985) that one can influence the way subjects spell pseudo-words by first presenting words which rhyme with the targets. For example, the pseudo-word [prein] tended to be spelled as PRAIN when preceded by BRAIN and as PRANE when preceded by CRANE. Analogies with real words can thus influence the assembly procedure in spelling pseudo-words (see also Frith, 1980; Marsh, Friedman, Desberg and Welch, 1980). Again, it is worth noting that the use of analogies in spelling does not deny the very existence of the assembly procedure: the processes of graphemic assembly must isolated and combine the relevant portions of activated words.

2. Development of the Procedures used in Word Recognition

Whereas structural models are useful to describe how the various components cope together during online processing, developmental models are needed to explain how the different subsystems come into being. Recent models (Marsh et al., 1980, 1981; Frith, 1985) postulate the existence of successive stages in visual word processing, each stage being characterized by the predominant use of one particular strategy. Both proposals actually have a lot in common, although Frith's description is more comprehensive. We shall first shortly describe the main features of Frith's model and then discuss some of the basic issues.

A stage model of reading acquisition

Three successive stages are depicted. The first stage is characterised by the use of a **logographic** strategy, based on rote memorisation of printed words. Subjects rely on visual features such as the global shape of the word, its length or the presence of salient letters. The order of the letters, as their phonological value may be almost ignored.

The second stage (called **alphabetic** by Frith) involves the predominant use of grapheme-phoneme correspondences. Simple rules would be acquired first; context-sensitive rules, by which the interpretation of each phoneme becomes dependent on its letter context, would follow.

The third stage is based on an **orthographic** strategy, which approximately corresponds to the direct access procedure used by skilled readers. Frith (1985) defines it as "the instant analysis of words into orthographic units without phonological conversion. The orthographic units ideally coincide with morphemes. They are internally represented as abstract letter-by-letter strings. These units make up a limited set that (...) can be used to create by recombination an almost unlimited number of words. The orthographic strategy is distinguished from the logographic one by being analytic in a systematic way and by being non-visual. It is distinguished from the alphabetic one by operating in bigger units and by being non-phonological" (p.306).

An additional assumption of the model is that normal reading and spelling development proceed out of step, with either reading or spelling acting as pacemaker of development. More precisely, Frith suggests that the alphabetic strategy would be first adopted for spelling, reading being still predominantly logographic; the orthographic strategy would develop first in reading, and would later on be transferred to spelling.

Finally, Frith (1985) argues that the three strategies necessarily follow each other in strict sequential order, and that each one is a necessary step for further development: "Each new strategy is assumed to "capitalise" on the earlier ones" (p. 307). For instance, she claims that "it may be crucial that the "goal" of instant word recognition (which is established in the logographic phase) is preserved while the child gets to grips with grapheme-by-grapheme conversion" (p.309).

Evidence for the existence of three strategies

Some children learn to recognize a few printed words before they acquire any knowledge of grapho-phonological correspondences and their behaviour fits well the description of the logographic strategy (Mason, 1980; Masonheimer, Drum and Ehri, 1984; Ehri and Wilce, 1985; Goswami, 1986; Seymour and Elder, 1986). This seems to be true both for some children who have merely been exposed to environmental print before formal reading instruction and for children taught with a look-and-say method. Seymour and Elder (1986) showed that look-say first-grade children discriminated between words on the basis of various visual features such as length or presence of salient letters, independently of their position (e.g. a child responded BLACK to the words LIKES and THINK and to the pseudo-words PJOEK and BKACL). The sub-morphemic correspondences between sound and letters were ignored: most reading errors consisted of words visually similar to the target; very few neologisms or regularisations were observed. Children most of the time refused to respond to unknown words, illustrating the non-productive character of the logographic strategy.

The development of grapho-phonological conversion mechanisms (the alphabetic strategy) is indicated by the ability to read aloud unfamiliar printed words and pseudo-words. Some findings reported by Marsh et al. (1981) illustrate the notion that children master simple grapheme-phoneme correspondences first and context-sensitive rules later on. They showed that second grade, fifth grade and college students did not differ significantly from each other in the accuracy of oral reading of simple CVC patterns (e.g. HAN) while second graders were inferior to fifth graders and college students for pseudo-words containing long vowel-silent E patterns (e.g. HANE) as well as for pseudo-words containing the conditional c-rule (e.g. C is pronunced [s] when followed by I, E or Y).

Several authors have observed that young children sometimes produce pseudoword pronunciations which do not correspond to the most likely product of grapheme-phoneme conversion, but are similar to exception words (e.g. YAVE pronounced as HAVE rather than as GAVE). This type of response could result from the use of correspondences based on large units, and should then arise late in the development. Such a trend has been observed in a few studies (Marsh et al., 1981; Zinna, Liberman and Shankweiler, 1986). However, other authors have shown that pseudoword pronunciation can be affected by lexical knowledge even in beginning readers (Baron, 1979; Goswami, 1986). It is thus presently unclear whether or not assembly mechanisms necessarily develop through a sequence of progressive sophistication. The typical pattern could result from teaching curricula rather than from cognitive constraints in the learning organism.

The hypothesis of a developmental shift from an alphabetic to an orthographic strategy is supported by empirical observations showing that grapho-phonological conversion processes are used more by younger than by older readers. For example, in a recent study (Alegria, Content and Leybaert, in preparation), we compared the oral reading times for four different lists of stimuli. Two lists comprised words, either monosyllabic in one list or plurisyllabic in the other; the other two lists consisted of pseudowords matched in length with the words. The rationale was that by comparing the differential effect of length on words and pseudowords, we would be able to get a hint of the use of word-specific orthographic knowledge: if children were using only the grapho-phonological conversions, the reading times would be similar for words and pseudo-words. The subjects were first, third and fifth graders, exposed either to a look-and-say or to a phonic method. The results showed a clear developmental trend: for first graders, the length effect was similar for words and pseudo-words, suggesting that these subjects assemble a pronunciation for both words and pseudo-words. On the contrary, third and fifth graders read words more rapidly than pseudo-words and the effect of length was more important for pseudo-words than for words. This may be taken as an indication that the use of word-specific knowledge or orthographic access increases between first and third grade, although the data are open to alternative interpretations. For instance, one could argue that the word advantage (or part of it) could stem, within an assembly process, from access to an output phonological form. Thus although both words and pseudo-words would be processed by grapho-phonological conversion, the difference would arise because only in the case of words would the result lead to a phonological representation which is familiar to the reader. Which interpretation is more satisfactory cannot be decided on the basis of the present data alone. However, there is converging evidence from other paradigms favouring the notion of an increase in the use of orthographic access.

Backman, Bruck, Hebert and Seidenberg (1984) compared second, third, fourth grade children and adult subjects in oral reading of frequent words containing regular and homographic spelling patterns. Regular spelling pattern (e.g. -UST, -ANE) have entirely predictable pronunciations, while homographic spellings (e.g. -OST, -AID) have multiple phonological correspondences (e.g. SAID/PAID; MOST/LOST). A reader who would rely solely on grapho-phonological correspondences in reading aloud, and would not use word-specific information, should read regular words correctly and experience difficulties in reading homographic spelling patterns; furthermore, the misreadings of exception words should take the form of regularisations (reading HAVE as [heiv] for instance). On the other hand, a reader who would rely on word-specific information should show no difference between regular and homographic words. In fact, younger children were worse with the homographic words than with the regular words, indicating that their reading performance is largely mediated by spelling-to-sound correspondences. The performance of fourth graders and adults did not vary with the type of words, suggesting that they used a direct, orthographic procedure to identify these frequent words. Further evidence for the decrease of indirect access with the development of reading ability has been reported by Doctor and Coltheart (1980) and Reitsma (1984). In all these experiements, however, beginning readers' performances also showed evidence of orthographic access. For example in Backman et al.'s experiment, about 25% of the exception words were read correctly by the youngest group. Thus even if at some point in reading acquisition children mainly use an alphabetic strategy, they also can rely on the orthographic access system, for a limited set of familiar words.

Temporal and causal relationships between strategies

Various lines of evidence thus support the existence of the three strategies postulated by Frith. The next question concerns the causal relationships between them. The view taken by Frith amounts basically to two claims: that a logographic strategy is necessary for the development of grapheme-phoneme conversion processes; that the assembly processes are necessary for the development of an efficient orthographic lexicon.

The strong assumptions related to the sequentiality of the stages require one preliminary comment. Written language is the product of a relatively recent cultural evolution, and there is no reason to believe that it should rely heavily on specific hard-wired biologically determined resources. While one might accept the idea of a natural sequence of stages through which all children should pass in first language acquisition, there is no reason to expect the same to be true in written language acquisition. In fact, given the large differences in writing principles in different languages, one should probably expect the developmental sequence to be largely influenced by cultural factors.

What we would like to argue is that: a) there is no compelling reason, neither on theoretical nor on empirical grounds, to believe that the logographic strategy is an indispensable stage in reading and spelling acquisition, and b) that there is evidence favouring the notion that grapho-phonological correspondences might play an important function in the build-up of the orthographic lexicon and the acquisition of skilled word recognition.

A. the role of the logographic strategy

The occurrence of a logographic reading stage is probably strongly determined by reading instruction and favoured by a look-and-say method (see Barr, 1974-1975 for empirical evidence on this point). It is not clear why it would be necessary to know some sight words before being taught correspondences between letter groups and sounds. Moreover, there is no evidence that the size of sight vocabulary is a powerful determinant of code breaking. One weaker version of the hypothesis would say that children who have developed a logographic strategy would later develop the orthographic access more rapidly than other subjects. However, the data from our developmental study (Alegria et al., in preparation) do not support this hypothesis: the word advantage was very similar in the whole-word and in the phonic group, and did not seem to appear earlier in the whole-word classrooms.

B. the role of the alphabetic strategy

The use of letter-sound knowledge may influence reading acquisition in several ways. First, indirect access may serve as a generative procedure for reading words for which an orthographic address is not yet available. Children who have mastered grapho-phonological correspondences can read and understand any regular word which already exists in their (phonological) lexicon even without having ever seen it in print before. In this sense, the acquisition of a conversion procedure allows the child to become rapidly an autonomous reader. Similarly, grapho-phonological knowledge provides the child with a mechanism for initiating the process of spelling, at least for regular words: he can use correspondences in order to generate letters associated with the sounds he hears in spoken words.

Several authors raised the possibility that mastery of grapho-phonological correspondences would allow the beginning reader to create orthographic representations in which the identity of the letters and their sequence is fully represented. Jorm and Share (1983) suggested that the use of grapho-phonological regularities can serve as a self-teaching device for developing orthographic representations in the lexicon. Their suggestion was simply that each successful application of indirect access acts as a learning trial, creating an association between the orthography of the printed word and the phonological representation which has been accessed. Some authors have also suggested that letter-sound correspondences could act as a mnemotechnic device to facilitate the retention of orthographic knowledge in memory, and might thus act as an important tool for the rapid construction of orthographic entries in the lexicon (Ehri, 1980; Ehri and Wilce, 1985; Content, Morais, Alegria and Bertelson, 1986). If one already knows for example that the letter P stands for the sound [p] and that the digraph CH stands for the affricate [č], there is much less work to memorize the orthographic pattern for PEACH or CHEAP than if these correspondences were unknown. General orthographic knowledge which is useful for setting up orthographic representations includes not only information about single letter-sound relations but also information about more complex functional spelling patterns, including morphemic units and common spelling patterns shared by sets of rhyming words (i.e. AIR, PAIR, CHAIR, HAIR).

This view is supported by different lines of research. First, a strong relation had been demonstrated between speech segmentation abilities and reading acquisition. To learn to read and to spell, children must be able to appreciate explicitly the relation between the orthographic signal and the linguistic units it represents. As researchers from the Haskins Laboratories have pointed out about 15 years ago (Mattingly, 1972; Liberman, 1973), this may be particularly difficult in the case of an alphabetic orthographic which represents the internal structure of the spoken word at an abstract, morpho-phonological level.

As a matter of fact, numerous studies carried out on beginners readers showed strong correlations between performance in speech segmentation tasks and reading tests, even when general factors such as intelligence and socio-economic status are controlled. Furthermore, the hypothesis that speech segmentation abilities directly influence reading development is supported by several training studies (see Morais, Alegria & Content, 1987 for review and discussion).

A second line of evidence comes from comparisons of good and poor readers. Several studies have shown that poor readers, classified on the basis of reading comprehension tests, are less efficient than good readers in word recognition tasks. Perfetti and his collaborators (Perfetti and Hogaboam, 1975; Hogaboam and Perfetti, 1978; Perfetti, Finger and Hogaboam, 1978) have convincingly shown that good and poor readers differ in the naming times for written words and pseudowords. In most experiments, larger differences are observed for low frequency words and pseudowords than for high frequency words, supporting the notion that assembly processes is one locus of difficulty in poor readers.

Backman et al. (1984) found that the difficulty observed with the homographic words persisted for a longer time in poor than in good readers, indicating that the poor readers rely on spelling-sound correspondences for a longer period than good readers and rely less on the direct access system. On the other hand, skilled readers are also better in the use of grapheme to phoneme correspondences than less skilled readers. For example, the proportion of regularisation errors made on exceptional words was smaller in poor than in good readers. The efficiency of the assembly procedure seems to develop with reading ability, the less skilled readers looking like younger subjects.

Similarly, the efficiency of sound-to-letter conversion discriminates between good and poor spellers. Waters, Bruck and Seidenberg (1985) tested third-grade good and poor spellers with several sets of words. The spelling was entirely predictable from the pronunciation (regular words) in one set and not in the others (irregular words). All subjects used sublexical correspondences, since the degree of predictability influenced the ease of spelling. Poor spellers made more errors than good spellers on the irregular words, suggesting some inefficiency in the use of the visual-orthographic strategy. Moreover, they also appeared less proficient in the use of sound-to-letter knowledge: their error rates on regular words and pseudo-words exceeded those of good spellers, and a lower proportion of their errors were phonetically accurate renderings.

To conclude up to this point, theoretical and empirical arguments support the view that the use of linguistic regularities represented in an alphabetic orthography plays an important role in reading and spelling acquisition. Knowledge of grapho-phonological regularities allows to read and spell words for which no orthographic representation is available; efficient use of this knowledge may allow to develop orthographic representations rapidly for an important number of words. Inefficient mastery of the complex grapho-phonological correspondence system can thus explain part of the difficulties encountered by poor readers and poor spellers.

3. Procedures Used By Deaf Children In Reading And Spelling Words

At first sight, the reading ability of deaf subjects would constitute a decisive argument in the debate concerning the role of grapho-phonological correspondences in reading acquisition. These individuals, whose intelligence is said to be normal but who have poor abilities in oral language reception and production, are frequently assumed not to use phonological representations in cognitive activities like reading and writing, as the following quotes exemplify:

> "The deaf, of course, are incapable of thinking first of the sounds and then recalling a combination of letters which represent them and despite the system of encouraging them to spell by recalling combinations of letters associated with the lip-movements of others or their own acts of pronunciation, it seems probable-both from observing the deaf during spelling and learning tests and from study of their mispellings - that they depend mainly on another learning device. The device, I believe, consists in a more careful visual study of the

> words forms (...) and in the attempt to recall not the lip-movement-letter combination associations but the visual appearance of the word during attempts to spell words not yet firmly habituated as writing habits" (Gates and Chase, 1926, p. 296).

And, more recently,

> "silent reading could be accomplished without any knowledge of orthographic-phonological correspondences, as is the case for non speaking deaf persons who read" (Waters, Seidenberg and Bruck, 1984, p.293).

On such grounds, one would think that, if deaf subjects can learn to read and spell, then it would mean that word recognition and spelling could be acquired through visual means, without knowing how written language maps into speech. Contrary to this frequent assumption, we will argue first that various findings demonstrate the existence and the use of phonological representation in deaf persons. Furthermore, we shall present recent data which indicate that deaf children do develop assembling mechanisms for printed word recognition.

Phonological representations in hearing-impaired

It is erroneous to consider the deaf population as a "no oral language" group. To develop a phonological competence, information coming from several sources may be used by deaf subjects. They may use the information provided by the retroactive effect of their own articulation and by residual hearing. In French- and English-speaking countries, deaf children receive intensive instruction in speech and lipreading, and they develop speech skills with various degrees of success. At one end of the continuum, there are some children who develop a speech quite understandable by naive listeners. At the other end, some remain totally unintelligible (see e.g. Conrad, 1979). While the oral productions of deaf subjects are not perfect (see e.g. Hudgins and Numbers, 1942; Nickerson, 1975), they seem to be governed by rules (Dodd, 1976) and present similarities with those of younger hearing children (Oller and Kelly, 1974). Deaf people may also use visual linguistic cues which carry information about the phonological structure of speech. Dodd (Dodd, 1976; 1987; Dodd and Hermelin, 1977; Dodd et al., 1983) has underlined the role of lip-reading in the development of a phonological system by deaf children. The exposure to orthographic representations of written words in an alphabetic orthography may also allow deaf individuals to extract elements of the phonological and morphological structure. Finally, for those deaf persons with experience in manual communication, reliance on fingerspelling[3] may also provide a medium for acquiring phonological contrasts. All this information may allow the deaf child to internalize abstract phonological representations, i.e. representations specifying phonemes as composites of auditory, articulatory, labial and manual cues. The chance of internalizing such phonological representations will depend on the degree of hearing loss, on speech intelligibility, on the communication method to which the subject has been exposed as well as on the degree of expertise he has acquired in reading and spelling.

Deaf children use their phonological competence not only to produce speech; they may also use phonological information in cognitive activities. It has been shown that certain deaf subjects can access phonological representations when these facilitate a memorization task. Hermelin and O'Connor (1973) showed that a substantial number of profoundly[4], prelingually deaf subjects were better at recalling pairs of pictures with rhyming (e.g. chair - bear) than non rhyming names (e.g. girl - bus). The subjects who exploited the rhyme were more numerous among good articulators than among poor articulators. Dodd and Hermelin (1977) showed that profoundly deaf children memorize better pairs of words when these are homophonic (e.g. rain -

[3]Fingerspelling is a representation of the English (or French) alphabet, in which each letter is represented by a single handshape. Fingerspelled words are used in sign language in a number of contexts, e.g. to represent words (proper names, technical concepts) for which there is no signed equivalent.

[4]"Severe" and "profound" refer to the degree of hearing impairment. This is measured by taking the average of hearing loss at different speech frequencies. For example, according to the classification of the International Bureau of Audiophonology (that we followed to select the subjects in our experiments), the hearing loss is averaged on measurements for 500, 1000 and 2000 Hz. It is qualified as "severe" when it lies between 70 and as "profound" when it is greater than 90 dB.

reign) than when they are not (e.g. than - train)[5]. And more recently, Hanson and Fowler (1986) showed that college deaf subjects, who represent the most advanced readers among the deaf population, were able to perform a rhyme judgement task: they had to identify the rhyming pair, among two pairs of orthographically similar words (e.g. SAVE - WAVE and HAVE - CAVE). The performance of deaf subjects was higher than chance, although lower than that of hearing subjects. Other data indicate activation of phonological information in deaf subjects in situations in which it interferes with performance. Conrad (1970, 1973, 1979) and other authors (Hanson, 1982b, Hanson, Liberman and Shankweiler, 1984; Lichtenstein, 1983a, 1983b) showed that in serial recall of visually presented words, a proportion of deaf subjects present a rhyme effect as most hearing children do: performance is poorer with rhyming than with non rhyming words. Thus some deaf subjects translate the visual items into a phonological code, even if this recoding is in fact detrimental in one condition. In Conrad's experiments, the use of a phonological code was linked to the degree of hearing loss; as hearing loss increases, the proportion of subjects who use a phonological code and the magnitude of the rhyme effect decreases. It is also strongly correlated with the quality of the deaf subjects' articulation: with hearing loss controlled, the rhyme effect is more frequently found in deaf subjects who are good articulators than in those who are poor articulators.

In word recognition tasks, there is also evidence showing that deaf subjects sometimes access phonological information. As previously mentioned, the recognition of a word by the orthographic procedure may allow access to the corresponding **lexical** phonological representation. We (Leybaert, Alegria and Morais, 1982; Leybaert, Alegria and Fonck; 1983; Leybaert, 1987) used the Stroop paradigm (Stroop, 1935) to examine this question.

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[5]Note that their better performance in the homophonic pairs can not be accounted for by the use of an orthographic strategy. The orthographic overlap between THAN and TRAIN being the same to that between RAIN and REIGN. This methodological control also applies in Hanson and Fowler (1985)'s experiment, as well as in the Stroop experiment presented below.

Subjects were presented with strings of letters of different colors. They were told to identify the color of the strings of letters of different colors. They were told to identify the color of the strings and to ignore the letters. An interference effect is usually observed: the performance is worse when the letter sequence constitutes a color name presented in an incongruent color (e.g. RED printed in green ink) than when it constitutes a meaningless string (e.g. a sequence of consonants). We used two kinds of tasks. In the manual task the subject had to respond by pushing one button per color. The interference observed is assumed to result from the conflict between the semantic representation of the color and the semantic representation corresponding to the word, which has been involuntarily activated. In the vocal task the subject had to name the color aloud. The greater interference usually observed is assumed to result from the additional conflict between the phonological representation of the color name and the phonological representation of the printed word, which has been involuntarily activated. In several experiments, we showed that the interference effect was of the same magnitude in deaf and hearing subjects in the manual task. When a vocal response was required, the interference increased substantially in hearing subjects and in deaf subjects considered as good articulators, while it remained of the same size as in the manual task in subjects classified as poor articulators. These results suggest that access to semantic representations for familiar words is automatized[6] in deaf subjects as in hearing individuals. Moreover, it seems that activation of phonological representations may also be automatized in deaf subjects, at least in those who have developed an

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[6]More than ten years ago, some authors argued that an automatic process is characterized by several attributes: it does not encounter capacities limitations: it occurs while the subject's attention is directed elsewhere; it occurs involuntarily (see LaBerge and Samuels, 1974). The activation of semantic and phonological representation in the Stroop paradigm were supposed to meet these requirements. Since then, it has been shown that the Stroop effect is sensitive to the orientation of the subject's attention and to the limitations of his attentive capacities (see e.g. Kahneman and Henik, 1979; Kahneman and Chajczyk, 1983). The only criterion of automaticity that the Stroop effect meets is that it occurs involuntarily. We continue to refer to the processes involved in the interference effect as "automatic" in that restricted sense.

intelligible speech. These results indicate that profound prelingual hearing impairment does not preclude access to phonological information during reading. Such access is not confined to situations in which deaf subjects have time to laboriously recover learned pronunciations. It may occur quite rapidly, and even automatically in deaf subjects, suggesting that it is a fundamental property of their reading (see also Hanson and Fowler, 1986). This does not mean that deaf subjects use phonological representations in all the situations in which hearing subjects do. For instance, in a task requiring to detect a target letter in a text, silent letters are more frequently missed than pronounced letters by hearing subjects (Corcoran, 1966, 1967; Corcoran and Weening, 1968) suggesting that phonological representations of the words are being activated. In three studies with profoundly prelingually deaf children (Chen, 1976; Locke, 1978; Leybaert, 1980), no difference has been observed between detection of silent and pronounced letters, suggesting that deaf subjects carry out the task on a visual basis.

Phonological assembling processes in hearing-impaired

The second way by which deaf subjects may access phonological information during word processing, which interests us most in the context of the present discussion, consists in applying grapho-phonological conversion. There is no doubt that it is possible for deaf subjects to develop such a procedure and to use it in reading and writing verbal material. Their ability to read aloud pseudo-words, quasi not studied until now, and to write down pseudo-words (Dodd, 1980) gives evidence for this.

The question we want to address is thus whether deaf children differ from hearing ones in their use of grapho-phonological conversion in reading and writing. Deaf subjects might make less use of the assembly procedure, because it does not provide the same advantages to them than to hearing persons. The assembly procedure is useful to read and spell new written words only to people who have already internalized phonological representations for these items. This happens for the hearing child during primary linguistic development. In deaf children, there is more qualitative and quantitative variation in the type of linguistic representations internalized before entering school. Deaf children exposed to sign language will internalize many sign representations and a few fingerspelled representations. Children exposed to oral-aural methods of communication will internalize phonological representations which are neither as numerous nor as accurate as those of hearing children. So, even if deaf children apply grapho-phonological conversion to words which are unfamiliar in print, they will not necessarily get the meaning.

As a matter of fact, some empirical data show that deaf subjects do use the assembly procedure in reading and spelling. We looked (Leybaert, 1987) to this issue in reading with the Stroop paradigm already described. We compared the reaction time to identify the color of incongruent pseudo-homophones (like VAIRE and RAUZE, which are pronounced,in French, in the same way as the color names VERT -GREEN - and ROSE -PINK-) to the reaction time to identify the color of non-homophonic pseudo-words (like VOURE and RUIVE). As in previous experiments, the subject had to respond manually in one test and to name the color of the ink in another. In the vocal task, the pseudo-homophones gave rise to an interference effect which was of the same magnitude in deaf and hearing subjects, thus indicating that deaf children automatically assemble a phonological representation for pseudo-words. In the manual task, only hearing subjects displayed an interference effect. The absence of interference effect in deaf can be accounted for in terms of the time-course of the different access procedures. In the manual task, the interference effect can be attributed to a conflict between the semantic representation of the color and the semantic representation activated by the product of assembly. The lack of interference in deaf children can be explained by assuming that the activation of a semantic representation on the basis of assembled phonology takes more time than the activation of a representation of the color.

An experiment run by Hanson (1986) may also be relevant to discuss the issue of use of assembly procedure by deaf subjects in reading. It has been established that deaf subjects take advantage of sequential redundancy in recognizing letter strings (Doehring and Rosenstein, 1960; Gibson, Shurcliff and Yonas, 1970). Hanson (1986) examined whether the sensitivity to orthographic structure displayed by deaf subjects is due to their use of statistical redundancy, which can be acquired by visual means, or to their use of letter-sound knowledge, or to both. She asked deaf subjects, who were highly successful readers by comparison with most prelingually, profoundly deaf individuals, to judge whether a probe letter was present or not in a letter string presented tachistoscopically just before. The letter strings belonged to four conditions: strings of high summed single letter positional frequency that were either pronounceable (e.g. REMOND) or not (e.g. RMNOED); pronounceable (e.g. ENDROM) or non pronounceable (e.g. RDENMO) strings of low summed single letter positional frequency. The performance of the hearing and of "good articulators" deaf subjects was higher with the pronounceable strings than with the non pronounceable strings; the "poor articulators" deaf subjects demonstrated a small facilitation due to pronounceability, but this advantage was smaller than the one observed for the subjects in the two other groups. On the other hand, all subjects were more accurate for high than for low summed single letter positional frequency strings. Hanson (1986) argued that deaf subjects may exploit letter-to-sound information to identify letter sequence. The correlation observed in deaf subjects between the effect of pronounceability and speech intelligibility supports this interpretation. However, pronounceability could still be partly confounded with orthographic redundancy since bigram and trigram frequencies were not taken into account. It might thus be the case that "good articulators" are simply more sensitive to statistical redundancy than "poor articulators".

Concerning spelling, a recent study conducted by Hanson, Shankweiler and Fischer (1983) indicates that deaf subjects, who were college students with an exceptionally high reading level compared to the deaf population, make use of morpho-phonological regularities. We wondered whether Hanson et al.'s results are specific to deaf subjects who have attained a high level in reading and spelling or, alternatively, may be generalised to less advanced children. In a similar experiment, we (Leybaert and Alegria, in preparation) examined the performance of hearing and deaf second and fourth graders in spelling three sets of words. In the first set (regular words), the correct orthography directly reflected the phonological structure (e.g. BANANE, OURS, pronounced [bananə] and [urs]; in the second set (Morphologically-derivable words), the correct orthography could be derived from morphologically associated words (e.g. in French, OUVERT and PETIT, are pronounced [uvɛr] and [pəti], and the silent final T can be derived by thinking of words like OUVERTE [uvɛrtə], OUVERTURE [uvɛrtyrə], PETITE[pətitə], PETITESSE [pətitɛsə]; in the third set (opaque words), the words contained spelling patterns which have to be retained by rote memorization (ex. there is no other way than rote memorization to know that AUTOMNE [otɔnə] is spelled with a M and that OIGNON [ɔɲɔ̃] is spelled with OI). If the subjects use sound-to-letter knowledge, there should be a difference between regular and opaque words. If they take morphological regularities into account, performance should be better for M-derivable than opaque words.

The results indicate that second grade hearing children depended primariy on sound-to-letter knowledge. They spelled regular words accurately, but made a lot of mispellings for M-derivable and opaque words, for which their performance did not differ significantly. Fourth grade hearing children made less errors than second graders for M-derivable and opaque words. These data suggest two developmental changes in hearing children: first, fourth graders seem to use specific lexical information, which allows them to correctly spell more opaque words. Secondly, they start using morphological regularities, since their performance was significantly better for M-derivable than for opaque words. In both groups most errors were phonologically accurate, which is consistent with the hypothesis that hearing subjects rely strongly on sound-to-letter knowledge (cf. Waters et al. 1985).

The results of the two deaf groups also showed a large effect of spelling regularity: the percentage of errors was lower for regular than for opaque words. These data are at odds with the notion that deaf children simply read out spellings from the lexicon. If that was the case, they should spell the three sets of words equally well. Rather, the results suggest that knowledge of sound-to-spelling correspondences is used by deaf children.

However, deaf subjects, especially the youngest ones, seem to take less advantage from sound-to-spelling regularities. Their error rate for the regular words was much larger than for hearing subjects. A qualitative analysis of the errors provided some convergent indications. While a large part of the deaf subjects' errors consisted of mispellings compatible with the words' pronunciation, this type of error was less frequent in deaf than in hearing subjects. Several explanations may account for this observation. First, the phonological lexical representations may be less accurate in deaf than in hearing subjects. Some proportion of the mispellings made by deaf subjects parallels the production errors made in oral language by 2-3 year old hearing children (Catts and Kamhi, 1984) and by older deaf children (Dodd, 1976). In words containing consonant + plosive clusters (like CARTABLE [kartablə], MOUSTACHE [mustaʃə], ESCALIER [ɛskalje], a frequent mispelling consists in omitting the [s] or [r] (erroneous responses were, for example, MOUTACHE and ECALIER). It seems thus reasonable to suppose that part of the phonologically inappropriate spellings arise from inaccurate phonological representations.

Second, deaf subjects may use less (or less well) sound-to-spelling information. A non negligible proportion of deaf subjects' mispellings consisted of transpositions (e.g. spelling SPET for SEPT, SORPT for SPORT), while such errors were almost inexistent in hearing subjects (see also Hoeman, Andrews and Florian, 1976; Hanson, 1982a; Hanson et al., 1983 for similar observations). During the experimental session we also observed that some deaf subjects wrote down the letters in a non-contiguous way, leaving spaces for intervening letters (e.g. OR... GE for ORANGE). These observations suggest that deaf children rely more on a visual strategy and less on sequential information about the phonemes than hearing children do.

It is interesting to note that the proportion of phonologically accurate mispellings was significantly higher in the older deaf group than in the younger one, and was also higher in the "good articulators" than in the"poor articulators". It is very likely that the deaf children classified as "intelligible" have more accurate phonological representations; this may improve their ability to perform a linguistic analysis of words which would help them to extract the regularities between speech segments and their orthographic representations. Experience with the alphabetic orthography and/or better phonological representations may account for the fact that older subjects rely more on grapho-phonological conversion mechanisms.

As a conclusion, the results of our experiments together with findings by Hanson (1986) and Hanson et al. (1983) run counter the claim that deaf subjects only use visual strategies in written word processing. Both in reading and in spelling, they display evidence of recourse to sublexical speech-print correspondences, though their use of this knowledge source may be less extended and less efficient than in hearing children. The complementary results obtained by Hanson and by ourselves allow us to extend these conclusions in two ways. First, the use of grapho-phonological conversion is not limited to orally-educated deaf individuals, since the subjects tested by Hanson were native users of American Sign Language. Second, it is not restricted to deaf subjects who have developed a high level of skill in reading and spelling: while letter-sound knowledge probably improves with reading ability, it is already used by deaf children with little education.

4. Conclusions

In this paper, we have argued that the use of grapho-phonological regularities is important for the development of word recognition and spelling abilities in hearing children. A challenging hypothesis is that it would be possible to learn to read and write without making use of these regularities. Deaf children have often be cited as an example of such a possibility.

Theoretical and empirical arguments described above indicate that deaf subjects, as a group, do not depend exclusively on visual-orthographic strategies to read and spell words; they are able to use sublexical correspondences between orthographic and speech segments. Deaf subjects are not an homogeneous group in this respect: the use of grapho-phonological regularities is more extended - or more efficient - in deaf subjects whose speech intelligibility is higher. However, there are indications of the use of conversion processes even among those deaf subjects of low speech intelligibility. Thus, deaf children's reading can certainly no longer be considered as a valid argument against the importance of phonological processing in word recognition.

This conclusion does not exclude the possibility to find certain deaf individuals who might learn to read and write without relying on grapho-phonological conversion processes. Such cases seem to exist in the hearing population. Campbell and Butterworth (1985) recently reported the case of a young university student, R.E., who, while reaching a high level of achievement in standardized reading and spelling tests, displayed strikingly poor performance on pseudo-word reading. She also experienced difficulties in various tasks requiring analysis or manipulation of phonological units and in these tests, she relied upon orthographic representations more than upon phonology. Finally, in a word spelling test, she made more phonologically inaccurate errors than did the control subjects. Apparently, she succeeded in developing direct access for reading and spelling words without having developed much alphabetic abilities. One important question is whether this apparently rare pattern is due to exceptional compensatory abilities, for instance a particularly powerful visual memory, or whether it instantiates an alternative way of mastering the alphabetic system.

If this alternative were real, it would be particularly suited to deaf people. Therefore, one would expect to find among deaf subjects some good readers with very poor phonological skills. The next point to examine is thus whether the use of grapho-phonological correspondences plays a role in the development of reading and writing in deaf children, as it does in normally hearing children. If the knowledge of grapho-phonological regularities is related to the acquisition of literacy, correlations between its use and measurements of reading and spelling achievement should be observed in deaf children. This question has been little examined until now, but some indications are available in the literature. Hirsh-Pasek (1987) found that the reading ability of deaf subjects correlated significantly with their ability to segment fingerspelling handshapes. A very indirect, but non negligible argument is that in all studies conducted on deaf readers who have a high reading level, evidence for access to phonological information in reading has been found (Hanson et al., 1983; Hanson, 1985; Hanson and Fowler, 1986). This is striking, because these subjects were generally native users of ASL. Thus, phonological recoding is observed among deaf individuals who are good readers but whose primary linguistic development has not been in oral language. In one experiment described above (Leybaert & Alegria, in preparation), we showed that the acquisition of spelling in deaf children is accompanied by greater use of the linguistic regularities represented in the alphabetical orthography. The correlational nature of these findings does not allow to conclude that the ability of deaf children to use grapho-phonolofical regularities promotes their reading and spelling success. Alternative hypotheses may account for the same data: on one hand, experience with the alphabetic orthography itself could also serve to enhance the development of grapho-phonological regularities; on the other hand, a third factor may be responsible for both the development of reading and spelling and the use of grapho-phonological cregularities.

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