Spelling development in deaf and hearing children: Evidence for use of morpho-phonological regularities in French

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ABSTRACT: This study investigated the processes that deaf school children use for spelling. Hearing and deaf spellers of two age groups spelled three types of words differing in orthographic transparency (Regular, Morphological and Opaque words). In all groups, words that could be spelled on the basis of phoneme-grapheme knowledge (Regular words) were easier than words that could be spelled only on the basis of lexical orthographic information (Opaque words). Words in which spelling can be derived from morphological information were easier than Opaque words for older deaf and hearing subjects but not for younger subjects. In deaf children, use of phoneme-grapheme knowledge seems to develop with age, but only in those individuals who had intelligible speech. The presence of systematic misspellings indicates that the hearing-impaired youngsters rely upon inaccurate speech representations they derived mainly form lip-reading. The findings thus suggest that deaf subjects's spelling is based on an exploitation of the linguistic regularities represented in the French alphabetic orthography, but that this exploitation is limited by the vagueness of their representations of oral language. These findings are discussed in the light of current developmental models of spelling acquisition.

KEY WORDS: Deaf subjects, Lip-reading, Spelling

INTRODUCTION

While the notion that the orthography of French is an inconsistent system is still alive, there is a growing tendency to consider that it is a multileveled system containing regularities that penetrate deeply into the morphophonemic and lexical aspects of language (see Gak 1976). The French spelling system is broadly based on a set of phoneme-grapheme correspondences, but in many cases the same sound can be represented by more than one spelling pattern. Nevertheless, it is often the case that the use of a particular spelling is not entirely arbitrary, but is governed by various types of linguistic principles. The morphological relationships between words is one principle that allows to select a correct spelling from a pool of plausible alternatives. For example, while the spelling of the phoneme /ɛ̃/ is ambiguous in the two homophonic words **plein** and **plain** (/plɛ̃/) it can be derived that /ɛ̃/ is spelled *-ein* by relating **plein** to **plénitude** (/plenityd/) and *-ain* by relating **plain** to **aplanir** (/aplanir/). There are words, however, for which use of sound-spelling and morphological information do not allow one to select the correct spelling pattern, which has to be memorized. Some of these words have an irregular

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sound-spelling correspondence, meaning that the orthographic segment is consistently used to represent another sound (e.g. *e* never represents the phoneme /a/ except in **femme**). There are also words with exceptional spelling patterns, some of them borrowed from foreign languages (e.g. **clown, pyjama**) and others being survivals from the past (e.g. the *œ* in **œil**).

It follows that learning to spell such an orthography would require not only a knowledge of the relationships between phoneme and grapheme and a memory for those words or parts of words that are irregular, but also a knowledge of the morphemic structure of words. Since learning to spell seems to depend on preliminary knowledge of the morpho-phonemic analysis of the oral language, an interesting question is to know whether deaf children make use of these linguistic regularities for spelling. To put this issue in perspective, the theoretical models of spelling acquisition in hearing children will first be briefly discussed. The studies of deaf subject spelling will then be reviewed.

Frith (1985) and Seymour (Seymour & MacGregor 1984) have developed a model of reading and spelling acquisition in which the mastery of the written code occurs through three possible stages. A first, *logographic*, stage is characterized by the rote memorization of the word letters, independently of their pronunciation. In a second, *alphabetic*, stage, children use their knowledge of letter-sound correspondences. This procedure allows them to produce a spelling for words they have not seen before (Read 1971, Bryant & Bradley 1980). When reading and spelling experience increases, children shift toward a more sophisticated procedure, referred to as the *orthographic* stage. At this level, the spelling production system comes to be lexicalised, meaning that it takes account of the characteristics in the spellings of words that can not be derived from phoneme-grapheme associations. When children are at this point of development, they are able not only to memorize arbitrary characteristics of word orthographic patterns, i.e. irregularities, but also to rely on linguistic principles, like morphological relationships, to derive word spelling.

An important point of the developmental models is that there exists a developmental dependency between the achievement of an efficient spelling system based on phoneme-grapheme correspondences and later acquisition of a production system based on an orthographic strategy (Ehri 1980; Frith 1985; Seymour & MacGregor 1984). Subjects who are not able to learn phoneme-grapheme relationships would encounter difficulties in the acquisition of an orthographic mode of spelling organisation and be constrained to rely on the logographic mode of processing (see Seymour 1987, for a description of such cases).

Given the view that phonological abilities, and more particularly, the use of sound-letter correspondences, are critical for spelling development, the main question is whether children born deaf are able to make use of these correspondences when spelling. There is no consensus at present on this topic. Some authors have assumed that the lack of auditory input would preclude

the acquisition of phonological skills necessary for the normal development of spelling (see Gates & Chase 1926; Gibson, Shurcliff & Yonas 1970; Waters & Doehring 1990). For example, Gates & Chase argued that 'The deaf, of course, are incapable of thinking first of the sounds and then recalling a combination of letters which represent them' (1926: 296). Would this assumption be correct, it would mean that the deaf are limited to the use of visual (i.e., logographic) procedure for spelling.

This view has been challenged by other authors (see, e.g., Dodd 1980, 1987) who have argued that speech perception does not depend upon audition in a necessary sense, and that lip-reading can provide information that allows the acquisition of abstract mental representations of phonemes: '. . . people who are born profoundly deaf may, by lip-reading, gain enough information about the phonological structure of language to acquire such skills as speaking, recognizing rhyme and reading and spelling by phoneme-grapheme conversion' (Dodd 1987: 178). Indeed, while oral language is difficult to acquire for profoundly deaf people, most of them learn to speak through training in speech production, lipreading and use of residual hearing. The development of their phonological system is delayed and extended in time compared to that of subjects with no hearing impairment, as indicated by the fact that their errors in oral production are consistent and similar to those of much younger hearing children. This kind of observation leads to the predictions that: (1) deaf children would be able to develop the *alphabetic* strategy, based on the correspondences between letters (or groups of letters) and their representations of phonemes; (2) the acquisition of the alphabetic mode of spelling might be delayed and extended in time compared to hearing children; and (3) that their written productions would keep the trace of the ambiguities of the mental representations they derived from lip-reading. In addition, since there are large inter-individual differences in their ability to speak (Conrad 1979), a larger heterogeneity in the ability to make use of phoneme-grapheme correspondences would be expected in the deaf than in the hearing population.

Whether deaf children rely on phoneme-grapheme knowledge may be tested by comparing their performances for spelling Regular and Irregular words. The rationale of this method is that the children who rely on phoneme-grapheme correspondences would spell Regular words more accurately than Irregular ones; in addition, most of their errors would be phonologically accurate, meaning that the misspellings have the same pronunciations as the targets. On the other hand, spelling regularity should not affect the performance of subjects who are not relying on phoneme-grapheme rules. At the time the present experiment was started, three studies based on such a methodology were available. Dodd (1980, Experiment 1) found that while hearing children made fewer errors on Regular words than on Irregular words, the deaf subjects performed equally well with the two types of words. The qualitative error analysis showed that only 7.4% of the errors made by the deaf children were phonologically accurate, against 46.7% for the hearing group. So, there was no evidence that this sample of deaf subjects rely on

phoneme-grapheme rules when spelling words. It must be noted that the major source of errors (64.8%) for the deaf subjects were refusals, suggesting that deaf subjects wrote a response for very familiar words only. A reinterpretation of these results at light of the developmental models outlined above would be that these deaf subjects were relying on a logographic strategy, which allows to spell familiar words, but not less familiar ones.

Different results were found by Hanson, Shankweiler & Fischer (1983), who studied the spelling abilities of profoundly deaf college students. They compared the performances for three types of words differing in the degree to which spelling could be derived from the phonological structure. The correct spelling of level 1 words (e.g. **explode**) requires the use of knowledge of highly consistent sound-letter mappings; for level 2 words (e.g. **beginner**), correct spelling could be obtained by reliance on morphophonemic principles, i.e. knowledge of how to form suffixes; finally, the spelling of level 3 words (e.g. **Fahrenheit**) could only be partially derived by use of phonetic and morphophonemic structure: these words contain spelling patterns very unfrequent in English, which have to be retrieved from memory. The data show that deaf as well as hearing subjects found the more transparent words the easiest, the opaque words the most difficult to spell, and the morphophonemic words intermediate, suggesting that it is possible for profoundly, prelingually deaf subjects to develop a sensitivity to the phonological and morphological constraints of an alphabetic orthography. The error analysis shows that about half of the deaf subjects' errors (46.3%) were phonologically accurate, confirming that these subjects use the phonological structure of spoken words to generate spelling patterns. However, the percentage of phonologically accurate errors was much lower in deaf than in hearing subjects (81.6%), the deaf making more phonologically inaccurate substitutions (e.g. *torpado* for **torpedo**), omissions (e.g. *chamagne* for **champagne**) and insertions of a phonological segment (e.g. *torpedeo* for **torpedo**) than did the hearing subjects. Hanson et al. suggested that part of these phonologically inaccurate errors may reflect that the deaf subjects rely on phonologically inaccurate representations of individual words stored into their lexicon.

Finally, Waters & Doehring (1990: 366) reported that severely and profoundly deaf children who communicate orally were found not to show evidence for the use of sound-spelling information in spelling.

To summarize, the available reports suggest that the methodology which attempts to establish general contrasts between groups of deaf and hearing spellers may be of limited utility. What emerges from the reviewed studies is that there is an important heterogeneity regarding the processing characteristics of deaf individuals. One critical factor may be their linguistic competence, which expresses itself in their reading level. While Hanson's skilled deaf spellers at the college level seem to make use of phoneme-grapheme knowledge in spelling words, this pattern seems not to hold for Dodd's younger subjects nor for Waters & Doehring's (1990) less skilled students. It is tempting to suggest that deaf individuals who have a high reading level, which

is a sign of a well developed linguistic competence, would be more able to rely on linguistic regularities than those who have a low reading level. However, this conclusion is only tentative since it is based on a comparison across studies which used very different methodologies.

The goal of the present study was to directly investigate the development of the use of phonological and morphological information for spelling French words in deaf and hearing children. The performances of orally-educated deaf subjects and hearing subjects belonging to two age groups were compared in spelling three types of words equated for frequency and length but differing, as in the Hanson et al.'s study (1983), by the degree of orthographic transparency. The spelling of the Regular words could be straightforwardly derived on the basis of the use of highly consistent phoneme-grapheme mappings. A second class of items consisted of Morphological spellings. In French, there are many morphologically motivated spellings that are not sounded as they are spelled (e.g. 3rd person plural, plural of the nouns and adjectives). We chose to investigate the case of masculine nouns and adjectives that are spelled with a consonant which is not pronounced, but which is the same as the consonant pronounced in the feminine form (e.g. vert /vɛr/ – verte /vɛrt/, boulanger /bulãʒe/ – boulangère /bulãʒɛʀə/). The correct spelling of the masculine forms of these words can be obtained by analogy, if the speller accesses one or more model words that are similar in morphemic structure to the word to be spelled. The third class of items, the Opaque words, consisted of words for which the correct spelling cannot be derived entirely from use of morpho-phonological information, but has to be retrieved from the lexicon. By giving the same test to subjects differing in age and in ability level, individual differences in the use of linguistic information in spelling could be identified.

Two comparisons between the three conditions are of particular interest. First, the comparison between Regular and Opaque words. A better performance for Regular than for Opaque words would be the hallmark of the use of phoneme-grapheme relationships. This effect could vary differently with age for hearing and deaf subjects. For hearing subjects, phonological development typically take place during the preschool years (Aicart de Falco & Vion 1987), and phoneme-grapheme rules are generally mastered during the second year of formal schooling (Leybaert & Content 1995). Therefore, no noticeable change in the use of phoneme-grapheme knowledge was anticipated in these subjects. On the other hand, since the phonological system in subjects with deafness is not entirely developed at the onset of reading (see Dodd 1976) and is likely developing during schooling years. The use of phoneme-grapheme rules might be expected to develop with age in deaf subjects.

The second comparison concerns Morphological and Opaque Words. If students learn to spell morphological words as unanalyzed whole words, there should be no difference between error rates for Morphological and Opaque words. On the other hand, if knowledge of the morphemic structure is drawn upon by the speller, Morphological words would be easier to spell than Opaque

words because segments ambiguous spelling could be derived by analogy with morphologically related words. Such words would be easier to spell correctly than ambiguous segments that have to be retrieved from the lexicon. Although the use of morphological knowledge for spelling seems of first importance for spelling development, there have been only a few investigations of that matter for hearing subjects, and all are in English. Marsh et al. (1980) found that the use of the same spelling for nonword pairs (e.g. cazical-cazicise) which are analogues to real word pairs (critical-criticise) was practically non-existent at the second grade, and showed a developmental increase to the college level. Carlisle (1985) showed that there is a developmental increase from the 4th grade to the 8th grade levels in spelling derived forms by reference to morphemic structure. Waters et al. (1988) found that words whose orthographic representations are predictable on the basis of their relation to another word (Morphologic words: e.g. grammar-grammatical) are better spelled than words that contain orthographic segments that rarely occur in English (Strange words: e.g. yacht) and less well than regular words. The same pattern holds from grade 3 to grade 6 level. So, on the basis of these studies, it is tempting to conclude that a major developmental shift in the use of morphological relationships in spelling occurs around the second grade in subjects with no hearing impairment: until the 2nd grade, children would not use the morphemic structure;[1] after the 2nd grade, subjects would begin to make use of morphological information, and this use would increase up to adulthood (see Fischer et al. (1985) for evidence of non-optimal use of morphological structure even in adults). In French, there has been, to our knowledge, no attempt to study the developmental course of the use of morphological information in spelling. Therefore, our only expectation was that in hearing subjects the difference between Morphological and Opaque words would be larger for 4th grade than for the 2nd grade subjects. An important issue was whether deaf subjects also learn to exploit the morphological regularities represented in the French orthography.

In addition to the evolution of spelling procedures with age, individual differences related to degree of hearing loss and speech intelligibility in the deaf will also be examined. It is obvious that deaf subjects' knowledge of oral language is a variable function, and that their ability to rely on phonological representations for reading and spelling is also variable. Several studies have already shown that severely deaf and profoundly deaf with intelligible speech display more access to phonological representations for reading than profoundly deaf with unintelligible speech (Chen 1976; Hanson 1986; Hanson & Fowler 1987; Leybaert, Alegria & Fonck 1983; Leybaert & Alegria 1993) as well as for memorizing (Conrad 1970, 1979). So, it is likely that the experience with oral language would also be related to the ability to use the word's morpho-phonological structure in spelling. We were thus prepared to observe that severely deaf and profoundly deaf people with intelligible speech would show a larger regularity effect and more phonologically accurate errors than those deaf with unintelligible speech.

METHOD

Material

The stimuli consisted of 41 French words, belonging to the three word classes defined above. The stimuli across the three classes were matched as closely as possible in terms of word frequency, number of letters and number of syllables. The correct spelling of the Regular words could be derived straightforwardly from their surface phonological structure, through the application of highly consistent phoneme-grapheme correspondences. There are few alternative legal spelling patterns for these stimuli. The Regular words were: **bleu, ours, pluie, fleur, porte, avion, bouche, cochon, banane, malade, armoire, voiture, cartable, montagne.** Their mean log frequency calculated in BRULEX (Content, Mousty & Radeau 1990) was of 36.2; their mean length in letters was of 6.1.

The Morphological words were similar to the Regular words except for the fact that they contain one final ambiguous segment that can be disambiguated through knowledge of the morphological relation with other words. For example, the word *petit* (/pəti/) contains a final t which is unpronounced but that is pronounced in morphologically associated words like **petite** (/pətitə/), **petitessse** (/pətitɛs/). The Morphological words were: **chat, fort, plat, vert, grand, froid, trois, assis, petit, gentil, ouvert, écolier, boulanger.** Their mean log frequency was of 39.5. Their mean length in letters was of 5.2.

The Opaque words contain one or more segments correct spelling pattern of which cannot be selected by use of the phoneme-grapheme correspondences, but has to be retained by rote memorization. Some of these words contain one phoneme that can be represented by several legal orthographic patterns, like the /ɛ̃/ in **train**, which could be spelled 'ain', 'ein', 'in', 'yn'. Other words contain one segment which is spelled in an irregular way, meaning that the correct spelling pattern is usually used to represent another phoneme. For example the /ɔ/ in **oignon** is spelled 'oi' while 'oi' generally represents the phoneme /wa/. Finally, some of the words, like **clown**, were borrowed words that contained spelling patterns that rarely occurs in French. The Opaque words were: **pull, loup, train, doigt, neige, verre, cahier, raisin, pyjama, orange, oreille, derrière, attention, escalier.** Their mean log frequency was of 37.2 and their mean length in letters 5.6.

Procedure

Subjects were given the test sheet pages for the experiment, in which the target words were suggested by a drawing and/or by a sentence context. The first letter of each word was given. For example, the word *jour* was suggested by the following sentence: '**La nuit il fait sombre, le j . . . il fait clair**'. The subjects had to write the words down.

Hearing and deaf subjects were tested in their own classroom. If the subjects did not succeed in guessing a target, an alternative definition of the word was supplied. The words were not pronounced to the hearing subjects. The sign corresponding to the target word was produced for the deaf subjects.

Scoring

An incorrect response was scored if the response contained one or more errors.

A difficulty related to this procedure is that sometimes the subjects failed to figure out the target word and did not answer, or spelled out another word. Following Hanson et al. (1983) we didn't want to consider these productions as spelling errors, and we scored them as omissions. The following responses were considered as omissions:

(a) No response.

(b) A response (word or pseudo-word) that did not contain at least half of the letters of the target word. For example, for the target **brosse**, the responses *broche* and *brouche* were analyzed as responses, while the responses *peigne* and *brouchant* were scored as omissions. In Hanson et al.'s (1983) experiment, all the word responses were scored as omissions. This criteria could not be used in our experiment. Some of our targets were very short words, and an error on one or two letters may lead very often to the spelling of another word.

(c) A morphologically incorrect form of the target word in which the target was not completely represented (e.g. *ouvre* for **ouvert**). A morphologically incorrect form in which the target is completely represented (e.g. *fleurs* for **fleur**) was not scored as an omission but as an error.

Subjects

All hearing-impaired children from 3 schools of Brussels participated in the Experiment. Those subjects who had more than one third of the number of items of one condition scored as omissions (i.e., 5 or more) were excluded from the analysis because the mean established on the basis of too few observations may alter the estimation of the performance. This criterion excluded 20 young deaf children and 10 older ones. No hearing subject was excluded.

The final sample of 'young' deaf subjects consisted of 29 subjects in the first years of elementary school. Their age varied between 8.7 and 13.4 years (mean age: 10.9 years). Their mean hearing loss (computed on 250, 500, 1000 and 2000 Hz) was of 95 dB (range 72–120 dB). Among them, 10 were severely deaf, with a hearing loss between 70 and 90 dB, and the 19 others were profoundly deaf with an hearing loss greater than 90 dB in their better ear.

The final sample of 'older' deaf subjects consisted of 44 children of the second half of the elementary school or the first half of the secondary school. Their mean age was 13.3 years (range: 10.4–16.8 years). Their mean hearing

loss was of 93.8 dB (range: 70–116 dB). Among them, 17 were severely deaf, with a hearing loss between 70 and 90 dB and the others 27 had always been profoundly deaf (hearing loss higher than 90 dB) in their better ear.

After the experiment, the deaf subjects' teachers were asked to rate the intelligibility of the children on a five-point scale: (1) wholly understandable; (2) easy to understand; (3) about half understood; (4) very hard to understand; (5) effectively unintelligible. The subjects whose speech was rated (1), (2) or (3) were considered as intelligible, while those whose speech was rated (4) or (5) were considered as unintelligible. All but two severely deaf subjects had an intelligible speech. The mean speech intelligibility was of 2.4 for the younger group and of 2.1 for the older group of severely deaf subjects. In the younger group of profoundly deaf subjects, 11 children had an intelligible speech (mean speech intelligibility = 2.6) and 8 had unintelligible speech (mean speech intelligibility = 4.3). In the older group of profoundly deaf subjects, 15 children had an intelligible speech (mean speech intelligibility = 2.6) and the other 11 had unintelligible speech (mean speech intelligibility = 4.1). All deaf subjects had a full-time oral education.

The younger control group consisted of 20 second grade hearing children. Their mean age was 7.5 years (range: 6.10–8.5 years). The older control group consisted of 23 fourth grade hearing children with a mean age of 9.1 years (range: 8.0–10.8 years).

RESULTS

The mean percentage of errors for the four groups of subjects and the three types of words is shown in Figure 1. A 2 (age, between subjects) × 2 (group, between subjects) × 3 (word class, within subjects) ANOVA has been performed on these data. The main effects of Age [$F(1,112) = 77.13$; $p < 0.001$], Hearing status [$F(1,112) = 7.01$; $p < 0.01$] and Type of Words [$F(2,224) = 116.14$; $p < 0.001$] were all significant. Also significant were the two-way interactions between Age and Type of Words [$F(2,224) = 25.76$; $p < 0.001$] and Hearing status and Type of Words [$F(2,224) = 18.38$; $p < 0.001$], as was the three-way interaction between Age, Type of Words and Hearing status [$F(2,224) = 9.77$; $p < 0.001$].

This general analysis was supplemented by analyses made up at each age level. In younger subjects, the regularity effect was significantly greater for hearing than deaf subjects [$F(2,94) = 18.03$; $p < 0.001$]. However, the effect was significant for both groups. Newman-Keuls tests performed separately for hearing and deaf subjects, revealed the same pattern in both groups: R < M = O. In deaf subjects, 39.9% (R) < 55.8% (M) = 55.9% (O). In hearing subjects, 12.2% < 42.5% (M) = 58.9% (O). This pattern is characteristic of a sensitivity to phoneme-grapheme regularity, and, at the same time, of a lack of use of morphological knowledge to derive word spelling.

In the older group, the interaction between Hearing status and Type of

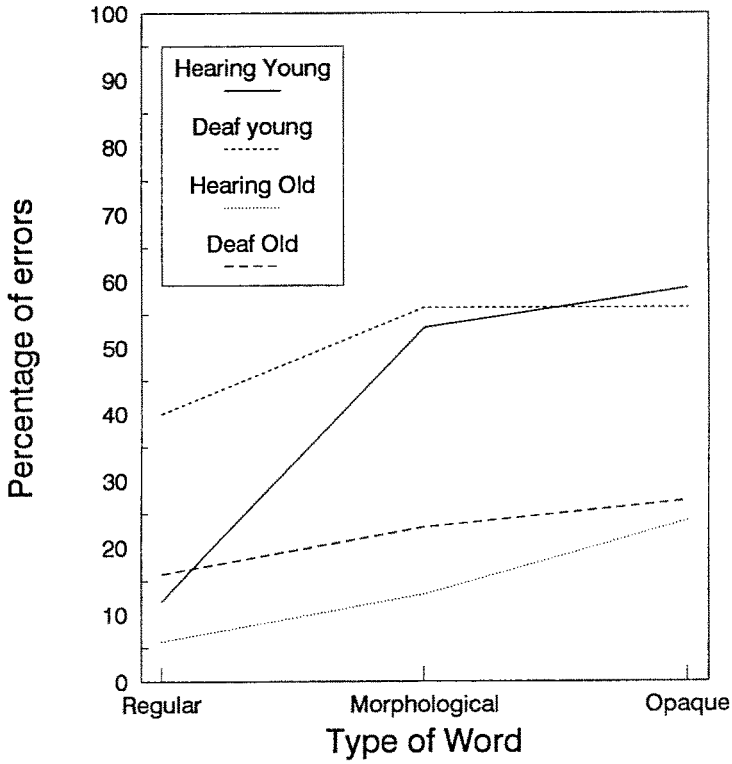

Figure 1. Mean percentage of errors as a function of type of words.

Words was not significant [$F(2,130) = 2.20$; $p > 0.10$]. The post hoc analysis revealed that the three Types of Words significantly differed from each other ($p < 0.01$) in these subjects: R < M < O. The mean percentage of errors were respectively 6.2% (R), 13.3% (M) and 24.0% (O) for the hearing group of subjects and 15.9% (R), 22.6% (M) and 26.8% (O) for the deaf group of subjects.

Error types

To gain further insight into the spelling process, the errors were broken down into different categories:

– phonological substitutions: the misspelling constitutes a legal orthographic pattern for the word pronunciation (e.g. *doi* for **doigt**; *dèrière* for **derrière**; *atansion* for **attention**). The errors showing that the subject had analysed the correct phoneme but in which the selected grapheme was pronounced quite differently in the context were nevertheless considered as phonological substitutions (e.g. *pigama*, *banan*).

– non-phonological substitutions: the misspelling has a different pronunciation than the target but the phonological structure of the target (in terms of number of syllables and number of phonemes) is respected in the response: e.g. *pourte* for **porte**; *pichamat* for **pyjama**; *rase* for **raisin**;

– transpositions: the misspelling contains the letters of the target but the order of the letters is not respected: e.g. *mongnte* for **montagne**; *belu* for **bleu**; *niege* for **neige**;

– others: the misspellings that did not enter into the previous categories; this includes omission of one letter (e.g. *feur* for **fleur**) or of more letters (e.g. *carble* for **cartable**), insertions (e.g. *corchon* for **cochon**) as well as misspellings for which it is more difficult to figure out the relationship with the target (e.g. *écaisse* for **escalier**; *pyge* for **pyjama**; *atouse* for **attention**).

These categories addressed the whole misspelling, and not the segments. For example, the phonological substitutions only comprised the spelling patterns pronunciation of which are identical to the target. The words of which several segments were incorrectly spelled, with only one of them being a phono-logical substitution, were included in the 'other' errors. Our scoring of phonologically accurate errors was thus quite conservative. But it seems more adequate for our error collection. Indeed, when several errors occur on the same words (like in *écaisse* for **escalier**), it is difficult to decide how many segments are phonological substitutions, non-phonological substitutions, transpositions, omissions, or insertions. The complete listing of the incorrect responses for deaf and hearing subjects, along with its classification in this study, is available from the authors.

The total number of errors in each category and the mean percentage of error in each of the different categories appears in Table 1 as a function of age and hearing status groups. It is easy to see that while the majority of errors in the hearing subjects (younger and older) consisted of phonological substitutions, the errors of the deaf subjects were divided up into phonological substitutions, non-phonological substitutions, transpositions, and 'others' errors. The distribution of errors in hearing and deaf subjects was significantly different for the younger groups [$\chi^2(3) = 403.7$; $p < 0.0005$] as well as for the older ones [$\chi^2 = 143.1$; $p < 0.0005$]. To be able to examine the type of error independently of its frequency of occurrence, the different types of errors have been expressed in percent out of the total number of errors for each subject. The mean error percent of each type for each group is also displayed in Table 1. The percentage of phonological substitutions is lower in deaf than in hearing subjects for the younger groups [$t(47) = 15.69$; $p < 0.0001$] as well as for the older ones [$t(63) = 8.08$; $p < 0.0001$].

In deaf subjects, the distribution of errors of the younger group significantly differed from the distribution of errors in the older group [$\chi^2(3) = 33$; $p < 0.005$]. More particularly, the percentage of phonological errors is lower in the younger group than in the older one [$t(63) = 8.08$; $p < 0.0001$]. The hearing subjects did not display such differences.

Table 1. Mean percentage (standard deviations are given in parentheses) and number of each error type for the younger and older deaf and hearing subjects

		Younger subjects		Older subjects	
		Deaf	Hearing	Deaf	Hearing
Phonological substitutions	$\bar{x}$	21.8	90.6	37.7	88.2
	SD	(17.7)	(9.9)	(23.8)	(23.2)
	N	98	286	113	122
Non phonological substitutions	$\bar{x}$	20.7	3.6	26.2	9.1
	SD	(11.0)	(6.4)	(18.2)	(23.2)
	N	111	11	98	5
Transpositions	$\bar{x}$	7.1	1.1	7.8	0.40
	SD	(6.6)	(3.7)	(10.9)	(1.8)
	N	34	3	32	1
Others	$\bar{x}$	50.4	4.7	28.3	2.2
	SD	(17.9)	(5.0)	(19.4)	(5.2)
	N	276	17	125	6

Individual differences among deaf subjects

To examine the error pattern in function of degree of hearing loss and speech intelligibility, the deaf group of subjects was split into three sub-groups: severely deaf, profoundly deaf with intelligible speech and profoundly deaf with unintelligible speech. An ANOVA was performed on the error rates of these sub-groups for Regular, Morphological and Opaque words. Neither the group factor nor the Group by Type of words interaction were significant.

The three sub-groups of deaf subjects have also been compared from the point of view of the nature of their errors. The number and percentage of errors of each category as a function of age of subjects appear in Table 2 separately for severely deaf, profoundly deaf with intelligible speech and profoundly deaf with unintelligible speech.

The difference between the distribution of the errors among the three sub-groups was marginally significant [$\chi^2(6) = 12$; $0.05 < p < 0.10$] in the younger subjects, but became more important and highly significant in the older subjects [$\chi^2(6) = 24$; $p < 0.001$].

Analyses have been performed on the effect of age on the distribution of errors in each sub-group of deaf subjects. Among the severely deaf and the profoundly deaf with intelligible speech, the distribution of errors was different in the younger and the older groups [$\chi^2(3) = 8$; $p < 0.05$; and $\chi^2(3) = 29$; $p < 0.0005$ respectively]. For the profoundly deaf subjects with unintelligible speech, however, there was no significant effect of age on the distribution of errors [$\chi^2(3) = 7$; $0.05 < p < 0.10$]. The difference between the proportion of phonologically accurate errors in the younger and the older groups was significant for the profoundly deaf children who had an

Table 2. Mean percentage (standard deviations are given in parentheses) and number of each error type for the younger and older severely, profoundly intelligible and profoundly non intelligible deaf subjects

		Younger subjects			Older subjects		
		Severely (N = 10)	Profoundly intelligible (N = 11)	Profoundly non intelligible (N = 8)	Severely (N = 17)	Profoundly intelligible (N = 15)	Profoundly non intelligible (N = 12)
Phonological substitutions	$\bar{x}$	30.9	18.4	15.1	46.0	43.2	18.9
	SD	(23.8)	(13.8)	(8.2)	(28.3)	(15.8)	(13.9)
	N	41	38	19	49	43	21
Non phonological substitutions	$\bar{x}$	18.5	23.5	19.3	19.3	32.5	28.3
	SD	(9.3)	(12.4)	(11.6)	(16.8)	(16.1)	(20.4)
	N	32	51	28	37	33	28
Transpositions	$\bar{x}$	6.9	4.7	10.6	8.2	2.4	13.8
	SD	(6.6)	(5.8)	(6.7)	(11.6)	(6.4)	(11.6)
	N	11	9	14	14	2	15
Others	$\bar{x}$	43.7	53.3	55.0	26.5	21.9	38.9
	SD	(24.8)	(14.0)	(10.1)	(18.9)	(21.8)	(13.1)
	N	88	108	80	54	27	44

intelligible speech [$t(24) = 5.01$; $p < 0.001$], but not for the profoundly deaf children who had an unintelligible speech [$t < 1$], nor for the severely deaf subjects [$t(25) = 1.3$].

Nature of the errors

An inventory of non-phonological substitutions and omissions has been performed on deaf subjects' errors. We will describe below some 'systematic' errors, in the sense that they appeared in more than one subject or in more than one word. Only the errors made on consonants were considered.

There was a lot of confusions between the graphemes representing the four consonants /s/ /z/ /ʃ/ and /ʒ/, resulting in changing either the voicing feature or the place of articulation feature of the consonant. The graphemes **j** and **g** were often substituted by *ch*, resulting in a devoicing of the consonant /ʒ/ into /ʃ/: this error was made in **pyjama** by 12 subjects (e.g. *pichama*), in **orange** by 2 subjects (e.g. *oranche*), in **boulanger** by 3 subjects (e.g. *boulanche*); **j** was also substituted by *s* or by *z* (changing in place of articulation of /ʒ/ into /z/) in pyjama by 6 subjects (e.g. *pisama*: *pizama*:). The grapheme **ch** was replaced by *g* (voicing of /ʃ/ into /ʒ/) in **bouche** by 3 subjects (e.g. *bouge*), and by *ss* (changing of place of articulation from /ʃ/ to /s/) by 2 subjects in **bouche** (e.g. *bousse*) and by 1 subject in **cochon** (*coussou*). The graphemes **ss** and **ti** are substituted with *ch* (changing of place of articulation from /s/ to /ʃ/ in **assis** by 2 subjects (e.g. *aché*), and by 2 subjects in **atten-**

tion (e.g. *atonche*). The grapheme **s** /z/ is replaced by *ss* (devoicing of /z/ into /s/) by 8 subjects in **raisin** (e.g. *raissin*).

There appeared to be some other substitutions between the graphemes representing voiced and voiceless pairs, like **t** and **d**, **f** and **v**: 2 subjects made such a substitution in **attention** (e.g. *adencon*) and in **gentil** (e.g. *gindi*); **ouvert** (3 subjects; e.g. *oufer*) and **avion** (2 subjects; e.g. *afeo*) were misspelled with a **f**. There were also substitutions between the letters representing the nasal-non-nasals pair **m** and **b**: **armoire** (5 subjects; e.g. *abois*) and **pyjama** (1 subject; e.g. *pichaba*) were spelled with a **b**. Other systematic substitutions (between m and n) involved the changing of place of articulation in nasals: **armoire** (2 subjects; e.g. *arnoire*).

Among the errors 'others', some omissions also seem to be systematic and to have a phonological basis: the graphemes **r** /r/ and **s** /s/ are frequently omitted in pre-consonantic position: this error was made by 15 subjects in **cartable** (e.g. *catable*), by 14 subjects in **armoire** (e.g. *amoire*), by 1 subject in **porte** and by 8 subjects in **escalier** (e.g. *ecalier*). The graphemes **r** was omitted in post-consonantic position by 2 subjects in **froid** (e.g. *fois*), by 1 subject in **grand** (e.g. *gend*) and by 1 subject in **train** (*tain*); the grapheme **l** was omitted by 1 subject in **pluie** (e.g. *puis*), by 3 subjects in **fleur** (e.g. *feur*) and by 2 subjects in **cartable** (e.g. *catabe*). It must be noted that young hearing subjects also omitted sometimes the graphemes **r** and **l** in post-consonantic position in the words **pluie** (5 subjects) and **armoire** (1 subject).

DISCUSSION

The purpose of this study was to investigate to what extent deaf children drew upon linguistic (phoneme-grapheme and morphological) knowledge when spelling words. Because we thought that the possibility of significant differences among deaf subjects is a real one, we adopted a presumption of heterogeneity at the outset of this research. We assumed that reliance on morpho-phonological knowledge may vary as a function of subject characteristics like age, hearing loss and speech intelligibility. The development of the reliance on morpho-phonemic structure was investigated by examining how deaf and hearing subjects of two age groups spell three types of words differing by their orthographic transparency, as well as by analysing the nature of their misspellings. In addition, the performances of deaf subjects were also examined in relation to their hearing loss and speech intelligibility.

It is apparent from the results that spelling difficulty is related to the transparency of the relationship between the phonological and the orthographic forms in the four groups of subjects and that this effect of orthographic transparency varies with age. In the younger groups, the percentage of errors for Regular words differed significantly from the percentage of error for Morphological and Opaque words, which were not statistically different, indi-

cating that both deaf and hearing young subjects rely on relationships between speech segments and graphemes for spelling. (We will comment later on the interaction between hearing status and the effect of regularity in the younger subjects.) In the older groups, the percentage of errors for Regular, Morphological and Opaque words significantly differ from each other, suggesting that deaf as well as hearing subjects rely not only on an analysis of the word pronunciation but also on deeper morphological relations represented in the orthography. These data are at odds with the claim that deaf subjects are limited to the use of visual, non linguistic strategies in spelling, because they would be deprived of any speech representations. Instead, our data support the opposite view, i.e. that deaf subjects do have representations of speech and that they are able, for spelling, to establish relationships between the phonological segments which constitute these representations and the graphemes which correspond to them. Our data thus extend Hanson et al's (1983) findings by indicating that the use of linguistic knowledge is not restricted to the best educated deaf subjects who were tested by these authors. They allow to affirm that it is possible for young deaf children who are in the process of literacy acquisition to make use of the relationship between their mental representations of speech and the French orthography.

The new and important findings of this study concern the developmental changes in the knowledge used by deaf and hearing children when spelling. A first change, common to both hearing and deaf subjects, concerns the use of morphological information. While younger subjects have a strong tendency to derive the spelling of a word from its surface phonological structure, older subjects seem to be able to derive the correct word spelling by accessing model words that are similar in morphemic structure. Our data thus support the view that the use of analogy based on morphological knowledge in spelling is developing after the second year of formal reading instruction (Marsh et al. 1980) and is still developing during the elementary school years in hearing subjects (Carlisle 1985; Waters et al. 1988). In addition, and perhaps more importantly, these data indicate that it is possible for subjects with deafness to make use of morphological knowledge in spelling. These data are compatible with the conjecture that it is the experience with the alphabetic orthography itself that promotes the awareness that the orthography represents the morphological relations between words (Liberman, Liberman, Mattingly & Shankweiler 1980) and this is true for deaf as well as for hearing subjects.

It must be noted that the mastery of morphological spelling may be accounted for by two different explanations. On the one hand, it is possible that the 'morphological' spellings require a high level of *linguistic* competence, which is more developed in the older than in the younger subjects. On the other hand, given the quantity of these non-transparent spellings, it is possible that children acquire this knowledge on the basis of a *statistical* analysis of morphological mappings. It has been shown recently (Brown & Loosemore 1994) that the development of regular and irregular spellings may be simulated by a connexionist architecture. It would be interesting

to investigate in future research whether the mastery of the 'rules' of morphological spelling may also be adequately simulated by this type of architecture.

A second developmental change concerns the use of phoneme-grapheme knowledge. This seems rather specific to deaf subjects: older deaf individuals seem to benefit more than younger deaf children from the existence of regularities between speech and graphemes. This is indicated not only by the lower error rate for Regular words displayed by the older group, but also, and more importantly, by the higher proportion of phonologically accurate errors in this group. These data support the hypothesis of a developmental delay in the acquisition of the alphabetic strategy by the deaf subjects. However, since the performance of older deaf subjects (i.e. their proportion of phonologically accurate errors) do not parallel that of younger hearing subjects, the notion that the spelling development of children with deafness is also deviant from that of normally-hearing children cannot be excluded.

The results strongly suggest the existence of an heterogeneity, related to speech quality, among the deaf population regarding the use of phoneme-grapheme knowledge. The data show that severely deaf, profoundly deaf with intelligible speech and profoundly deaf with unintelligible speech differ in the type of errors they made, and that the distribution of error type was significantly different for younger and older subjects in the former two groups but not in the latter. Sound-to-spelling knowledge seems to develop with subjects' age in those severely and profoundly deaf who had an intelligible speech, but not in those deaf who had an unintelligible speech. Given the correlational nature of this finding, it cannot be determined from this study how acquisition of spelling-to-sound regularity and speech intelligibility are linked, but several possibilities may be raised. It is likely that speech quality mainly reflects the mental model deaf subjects have of speech. So, intelligible deaf subjects would have more accurate representations of the segmental parts of speech than unintelligible deaf subjects. In consequence, intelligible deaf subjects would be more efficient in learning to perform a linguistic analysis of spoken word into segments and to make use of the correspondences between these segments and the graphemes that represent them. It is also possible that the phonological representations themselves become more accurate with time. This can be due to training in speech production and perception, and/or even to exposure to written material itself. Research has shown (Ehri 1984) that experience with the alphabetic orthography provides information that enhances the internal representations of speech segments in hearing subjects. The influence of orthography might be *more important* for deaf children, who have derived speech segments through lipreading phonological representations that are underspecified (see Leybaert 1993). This would occur particularly for those subjects who already possess such representations and could then serve to further enhance the use of phoneme-grapheme correspondences.

It is interesting to note, however, that the deaf subjects with poorly intelligible speech did not appear to be completely insensitive to the speech-to-

print regularities, since they also showed a better performance for Regular words than for Opaque words. It could be argued that the regularity effect exhibited by these subjects results from a difference between Regular and Opaque words in the degree of orthographic redundancy, part of the Opaque words containing orthographic patterns that rarely occur in French. Although this question cannot be resolved without further research that will control that aspect, two arguments already support the hypothesis that deaf subjects with poorly intelligible speech also make use of speech-to-print regularities. On the one hand, in our experiment, these subjects exhibited a small number of phonological substitutions. On the other hand, in a study in which the effect of spelling-to-sound regularity was manipulated independently of statistical orthographic redundancy, Hanson (1986) found that poorly speaking deaf subjects display some sensitivity to spelling-to-sound regularity, although to a lesser degree than intelligible deaf participants. These results can be understood if we remember that the poorly intelligible deaf subjects were not completely without speech ability; their speech proficiency was just less than that of the intelligible individuals; correspondingly, their ability to make use of the speech-to-print correspondences was somewhat less.

The conclusion that deaf subjects' spelling accuracy is based on their representation of speech seems to be invalidated by their error rate for Regular words as well as by the large proportion of phonologically inaccurate spellings, especially in the younger group of subjects. These differences indicate that hearing subjects take more advantage of the sound-to-spelling regularity than deaf subjects. However, while some of the errors made by the children with deafness may result from an inability to appreciate how the orthography maps onto the spoken language, it would be erroneous to conclude that this is true for all of them. The results strongly suggest that the systematic errors identified among the non-phonological substitutions and among the 'others' errors result from the use, by the deaf subjects, of phonological representations which are inaccurate as Hanson et al. (1983) have supposed. These misspellings may be due to intrusion of segmental errors in the speech of the subjects. This might be the case for the confusions between the graphemes representing /s/, /z/, /ʃ/, and /ʒ/: confusions between these four consonants are observed in deaf children's oral language (Hudgins & Numbers 1942) and are those that last for the longest time in 3 to 6 years old hearing children (Aicart-de Falco & Vion 1987). The origin of such confusions may be the ambiguities of the lip-read input. Indeed, most of the non-phonological substitutions 'look' similar to the targets (e.g. the responses *boche* or *banche* for **bouche**) and some substitutions between consonants that are undistinguishable on the lips occur, as between the voiced and voiceless consonants **t** and **d**, **v** and **f**, or between nasals and bilabials like **n**, **m** and **b**. The omissions of a consonant in a consonantic group (like in **froid**, **pluie**, **grand**) and at the end of a syllable (like the /r/ in **cartable** and **armoire**) seem also to have a phonological basis: they mainly concerned the phonemes /r/ and /l/ which have a particular position in the French phonological system, because of their articulatory

characteristics. Similar errors have been observed in the oral productions of hearing children aged from 3 to 6 years (Aicart-de Falco & Vion 1987) and, in this study, in the spelling of some of the younger hearing children. Such errors strongly support our hypothesis that deaf children rely upon speech representations for spelling.

These findings also support the view that lip-reading is a primary input in the constitution of speech representations in deaf individuals, as Dodd (1980; Dodd & Hermelin 1977) assumed. They indicate also that lip-reading and residual hearing are not sufficiently reliable to allow deaf subjects to acquire a full mastery of an alphabetic orthography.

The implication of these observations is that the notion of regularity between phonological forms and spelling patterns does not have the same meaning for deaf and hearing subjects. The spelling of a word may be predictable on the basis of the correspondences between phonological segments and graphemes to the extent that the input is the phonologically correct form. Our results suggest that deaf children sometimes apply regular correspondences to inaccurate and ambiguous phonological representations. This provokes a misspelling that is considered as phonologically inaccurate for hearing subjects but that might be an accurate phonological to orthographic transcription of the specific phonological representations held by deaf subjects. The methodological point here is that the percentage of correct responses for regular words and the proportion of phonological substitutions may not capture entirely deaf subjects' ability to make use of the phoneme-grapheme correspondences in spelling, while they are a true measure of this ability in hearing subjects. To establish what source of information deaf individuals rely on for spelling, it seems essential to perform an error analysis in which the errors are related to the specifics of the phonological system of the deaf. This may have important consequences on the interpretation of experimental data: for example, Campbell reported that if deaf subjects' misspellings are categorized as 'alphabetic' errors when they could be lipread as the target (e.g. *sponch* for **sponge**, *sissers* for **scissors**), 'no difference between deaf youngsters and reading-age matched children in the pronounceability of the errors they made appear' (1991: 109).

On theoretical grounds, two implications may be drawn from the present data. First, the fact that deaf subjects may form inaccurate orthographic representations, which are probably in accordance with their own speech (e.g. *pychama* for **pyjama**), illustrates how the acquisition of an efficient spelling system depends upon accurate phonological structures and how it might be hindered by the deficiencies of the mental representations of speech. This is not limited to deaf readers, but is also true for hearing subjects with deficiency in phonological abilities. Second, it is possible that the state of subjects' phonological system at the time of learning to read and write determines their predisposition to the mode of processing of written language. When phonological structures which are accurate enough are available, the deaf subjects would adopt an alphabetic/orthographic mode of spelling development, with

a certain delay in comparison with the speed of development of hearing children (and internalisation of some erroneous orthographic representations). On the other hand, if only very impoverished phonological representations are available, subjects would be compelled to rely more on a logographic mode of spelling. This may be the case more often for subjects whose speech remains unintelligible. In the present experiment, this is indicated by the fact that unintelligible deaf subjects made, on average, slightly more transposition errors than the other deaf subjects.

In summary, the present study indicates a relationship between deaf subject knowledge of oral language and the acquisition of a linguistic and analytic mode of processing written language. If this hypothesis is correct, it could have important implications for those who try to teach deaf children to read and spell, in particular in the decision of how to begin reading and spelling. This hypothesis has to be further validated in future research, in particular in longitudinal studies in which children's acquisition of phonological and metaphonological skills is studied before reading instruction has begun, and their progress in learning to spell (more particularly their use of speech to print correspondences) is studied during the early stages of acquisition.

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NOTE

1. Goswami (1988) put into question the notion that the use of analogy occurs late in the development of spelling. She found that the written presentation of clue words lead to significant improvement in spelling analogous words by children around 7 years, indicating that these subjects can use analogies to help them to spell new words. It must be noted, however, that these results do not invalidate the idea that the use of analogies, *on a morphological basis*, occurs later in development. Indeed, in Goswami's study, the clue word (e.g. beak) given as a basis for analogy was selected in order to share phonemically either the beginning (e.g. bean) or the end (e.g. peak) of the target word, but was never morphologically related to it.

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