Visuo-orthographic knowledge in deaf readers of French

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This study investigated visuo-orthographic knowledge in deaf readers of French compared to age-matched hearing subjects. More specifically, we were interested in knowledge related to the legal position of double consonants and to the fact that double consonants are much more frequent than double vowels in written French. We used a word-likeness choice task in which subjects had to determine which of two pseudo-words most resembled a real word in written French (e.g., *fellut* or *felutt*). The participants were 24 deaf students aged 10 to 18 and 24 matched hearing students. The main results indicate that deaf readers develop the targeted knowledge, but to a lesser extent than hearing controls. Different avenues are proposed to explain this difference.

Cette étude porte sur les connaissances visuo-orthographiques de lecteurs sourds comparés ici à des lecteurs entendants du même âge. Plus spécifiquement, on s'intéresse à savoir en quoi la position légale des doubles consonnes en français écrit est liée au fait que le doublement des consonnes est beaucoup plus fréquent que celui des voyelles. Nous avons eu recours à une tâche de jugement de plausibilité lexicale où les sujets devaient déterminer lequel de deux pseudo-mots était le plus plausible en français écrit (e.g., *fellut* or *felutt*). Les 48 participants (24 sourds et 24 entendants) étaient âgés de 10 à 18 ans. Les principaux résultats montrent que les sujets sourds acquièrent le savoir visé par l'étude, mais à un moindre degré que les entendants. Plusieurs explications possibles à cette différence sont discutées.

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Introduction

Many deaf students encounter great difficulties in learning to read (Marschark, 1997; Paul, 1998). It is estimated that at the end of their schooling, deaf readers reach, on average, the level of hearing of fourth graders (Holt, 1994; LaSasso, 1999). These learning difficulties have often been explained by inefficient development and use of phonological knowledge and processing involved in word recognition (for a review, see Musselman, 2000). Indeed, in alphabetic languages, the orthographic code is based on the segmental structure of the oral language. Considering that many deaf students have limited access to the oral language, their reading difficulties in word recognition are not difficult to imagine.

Most models of word recognition and its development consider word recognition in terms of phonological and orthographical processes (Frith, 1985; Coltheart, Curtis, Atkins and Haller, 1993; Gombert, 1997; Seymour, 1997; among others). In general, it is proposed that phonological processes are involved in reading new words and low frequency words and that orthographic processes are responsible for reading high frequency known words and irregular words, i.e., those which cannot be read through graphophonemic correspondences. As readers become more proficient, word recognition increasingly relies on orthographic processes, the development of which is based on prior efficiency of phonological processes. Considerable empirical and theoretical research has demonstrated the key role of phonological processes in reading development (Share, 1995; Gombert, 1997; Ehri, 1998; Colé and Spenger-Charolles, 1999; Goswami, 2002, among many others), which has led many researchers to investigate phonological processes in deaf readers. Studies have shown that some young deaf readers do use phonology (Dyer, MacSweeney, Szczerbinski, Green and Campbell, 2003; Transler and Reitsma, 2005; Kyle and Harris, 2006; Colin, Magnan, Ecalle and Leybaert, 2007), that older subjects manifest more phonological sensitivity than younger subjects (Harris and Moreno, 2004; Daigle and Armand, 2008), and that better readers are more efficient at using phonological processes than weaker readers (Harris and Moreno, 2006). In these studies, deaf subjects are less efficient at phonological processing than hearing controls. Other studies, however, have not found results of this kind, and therefore can not be used as evidence of phonological processing in deaf subjects (Waters and Doehring, 1990; Merrills, Underwood and Wood, 1994; Chincotta and Chincotta, 1996). In the latter studies, the authors concluded that their subjects were using non-phonological processes, also called visual processes or orthographic processes, without defining what exactly they called non-phonological processes. The general aim of this study is to investigate orthographic processing and, more specifically, aspects of visuo-orthographic knowledge involved in word recognition.

In their discussion of the processes involved in reading, Hagiliassis, Pratt and Johnston (2006) note that at times orthographic processing is defined in terms of operations and at others in terms of knowledge. These operations relate to the fact that orthographic representations are created, stored and accessed (Stanovich and West, 1989). Orthographic knowledge refers to what readers know about letter patterns allowed for a specific language (Perfetti, 1984). In order to process words at the orthographic level, readers must have knowledge of the orthographic system of the written language. Some of that knowledge is word specific. For example, to recognize the written word *book* at the orthographic level, the reader must know the specific letters to be included in the word and their order, in addition, obviously, to having already assigned a meaning to the string of letters according to its context. The knowledge of the orthographic system also involves some more general knowledge that is not specific to a word. For example, the sequence *ght* is possible in English as in *taught*, but not in French, or the sequence *nsw* is also possible in English as in the word *answer*, but not as the onset of a syllable. Those rules, specific or general, refer to the orthographic legality for a specific written language, i.e., what is or is not possible in the orthographic system.

Studying orthographic processing in deaf readers from the perspective of the orthographic knowledge involved in reading is very interesting for at least two reasons. First, depending on the orthographic knowledge targeted, it is possible to study processing that does not involve phonology (which generally causes problems for deaf readers). For example, in a task in which subjects are asked to determine whether, in written English, the pseudo-word *rall* is more probable than the pseudo-word *rral*, the readers must know that in this specific language the sequence *ll* is possible at the end of words (as in *call*, *ball*, etc.) and that *rr* is prohibited at the beginning. In this example, the pronunciation of both pseudo-words will have the same phonological structure. This orthographic knowledge that does not involve phonology will hereafter be called visuo-orthographic knowledge in order to clearly distinguish it from knowledge that is linked to phonology. Second, some of the knowledge involved in orthographic legality is not taught in class. In the case of deaf students, studying such visuo-orthographic knowledge does not require taking into consideration the still-ongoing debate between educational philosophies that guide the school practices that are often held responsible for deaf students' success or failure in reading/writing acquisition.[1] Indeed, according to some authors, this visuo-orthographic knowledge is learned implicitly through print exposure (Pacton, Perruchet, Fayol and Cleeremans, 2001; Gombert, 2003) and does not depend upon the educational approach used in class. Implicit learning of knowledge can be defined as the appropriation of features characterizing a situation without explicitly using knowledge of these features in an intentional manner (Perruchet and Gallego, 1997). If we consider that this type of knowledge related to orthographic legality is independent from phonology and develops gradually as readers encounter written material (as Gombert, 2003, argues), deaf students should show increasing sensitivity to orthographic legality with age, given the additional print exposure they have over time. In this case, it would be the frequency of contact with certain orthographic patterns that would drive implicit learning.

Studies investigating sensitivity to visuo-orthographic knowledge have mainly used a word-likeness choice task in which subjects must select which of two pronounceable pseudo-words is the most probable in the written language (see example above: *rall* vs. *rral*). Research using this task in English populations shows that primary school children and even preschool children are sensitive to visuo-orthographic knowledge related to orthographic legality (Cassar and Treiman, 1997; Hagiliassis *et al*., 2006). In their study, Wright and Ehri (2007) used a word learning task followed by a written word production task with material similar to that used in word-likeness choice tasks. The analysis of written errors also revealed sensitivity to visuo-orthographic knowledge among kindergartners and first graders. These studies show that visuo-orthographic knowledge develops very early and can be observed when children first encounter written material. Another interesting study using a word-likeness choice task (Siegle, Share and Geva, 1995) compared sensitivity to visuo-orthographic knowledge in dyslexic children matched to normal younger readers. The subjects ranged from first to eighth grade in reading. The results showed that dyslexic subjects were better at selecting the expected pseudo-word than controls. The authors interpreted these results in terms of a compensatory reading strategy among dyslexic subjects. Since dyslexic readers have difficulty in phonological processing, they would compensate with orthographic strategies. Although this explanation is quite plausible, the results can also be explained in terms of print experience. If visuo-orthographic knowledge develops through increasing exposure to print (Pacton *et al*., 2001; Gombert, 2003), it would be possible to observe more established visuo-orthographic knowledge in dyslexic subjects matched to younger normal readers since older dyslexic readers may have had more print exposure.

Concerning French readers, the work of Pacton and colleagues (Pacton *et al*., 2001; Pacton, Fayol and Perruchet, 2005) is also of great interest. Using a word-likeness choice task, Pacton *et al*. (2001) showed that young French readers in the study (Grades 1 to 5) were sensitive to the fact that double consonants are never placed at the beginning or the end of French words. The results indicated that this knowledge was applied to consonants that cannot be doubled — for example, subjects prefered *lawwix* over *lawixx* even though *ww* and *xx* do not exist in French. This study also showed that subjects were sensitive to the fact that consonants are doubled much more often than vowels, which are only very rarely doubled. For example, subjects prefered *tillos* over *tiilos*.

This knowledge was also applied to double consonants that cannot be doubled (*tajjil* over *tajiil*). The results of this study have been interpreted in terms of implicit learning of knowledge related to orthographic legality in French.

Research with deaf students has focused more on written word production or on orthography acquisition than on visuo-orthographic knowledge per se. Through different tasks requiring subjects to write words, studies have shown that phonology could not account for deaf students' errors as in hearing controls (Dodd, 1980; Padden, 1993; Leybaert and Alegria, 1995; Aaron, Keetay, Boyd, Palmatier and Wacks, 1998; Sutcliffe, Dowker and Campbell, 1999; Harris and Moreno, 2004). Moreover, error analysis revealed that deaf students' word production was influenced by knowledge of orthographic legality with respect to legal sequences of letters (Hanson, Shankweiler and Fischer, 1983; Aaron *et al.*, 1998; Olson and Caramazza, 2004). In a developmental perspective, Padden's (1993) study is of particular interest. The author investigated orthography acquisition in deaf students aged 4 to 10. Error analysis showed that errors at the beginning of words decreased at a younger age than errors at the end of words, which decreased more quickly than those in the middle of the words. This suggests a pattern in the development of orthographic representations which is linked to the position of letters in words.

Harris and Moreno (2004) looked specifically at visuo-orthographic knowledge in deaf students. The authors used a word-likeness choice task with 8- and 14-year-old deaf children learning English. The children had to choose the legal pseudo-word out of four pseudo-words (*powl*, *lowp*, *wplo*, *opwl*). In 8-year-old subjects, the results indicated that deaf students got lower scores than hearing chronological-age controls and hearing reading-age controls. In 14-year-old subjects, deaf students' scores were not different from those of hearing reading-age controls. Finally, younger deaf children obtained lower scores than older deaf subjects. These results suggest that deaf students can develop visuo-orthographic knowledge related to orthographic legality and with age may reach the level of knowledge of reading-age-matched hearing students.

The present study

To our knowledge, no studies have looked at visuo-orthographic knowledge using a word-likeness choice task in deaf readers of French. This would be of particular interest since French differs greatly from English in terms of orthographic regularity and, as a consequence, it is difficult to infer French readers behaviors or reading development based only on the study of English readers. The main objective of this study is to investigate visuo-orthographic knowledge in deaf readers of French of different ages matched to hearing controls with the same chronological age. This study follows the work of Pacton *et al.*

(2001) done with hearing readers. Like them, we used a word-likeness choice task in which subjects had to determine the most probable item out of two pseudo-words.

From the theoretical background, two general expectations can be drawn. If deaf students develop orthographical representations more rapidly for the beginning of a word compared to the end of a word, as Padden (1993) suggests, we should observe an effect for the position of the targeted letter sequences. Sequences at the beginning of items should give rise to better success rates than those at the end of items. Moreover, if as Gombert (2003) argues, sensitivity to visuo-orthographic knowledge is related to frequency of print exposure and develops implicitly, we should observe an age effect and an effect for frequency of letter patterns. Older students should show more visuo-orthographic sensitivity than younger subjects. In addition, frequent letter sequences should be better recognized than less frequent letter sequences.

Method

Participants

At the time of our study, few severely or profoundly prelingual deaf students without any additional handicap were registered in French-language schools in the Montreal area. All our subjects had Quebec Sign Language as their main communication mode and all were educated in special classes where instruction was given in sign language. All received parental approval before testing. All subjects were severely or profoundly deaf (hearing loss in the better ear of at least 70 db); none had a cochlear implant and none had deaf parents. In total, 24 deaf subjects participated in this study. They were grouped according to age. Three groups of eight children were created (group 1: 10–12 years old; group 2: 13–15 years old; group 3: 16–18 years old). These age groups correspond to the last cycle of primary school and the two cycles of secondary school.

Deaf subjects were matched on a one-to-one basis, on age, with hearing readers. The control group was then also made up of 24 subjects without reading difficulties according to their respective milieu. They were grouped exactly as the deaf subjects. The age difference between deaf and hearing subjects within each group was not significant (group 1: $t\ (14) = 0.80$, ns; group 2: $t\ (14) = 0.94$, ns; group 3: $t\ (14) = 0.11$, ns).

All subjects first completed a computerized reading comprehension test (Ciesielski and Reinwein, 1989).[2] Since reading level is usually related to age, we correlated reading scores with readers' ages. The results showed that reading scores and ages were very significantly correlated in our deaf subjects, $r = 0.722$, $p < 0.001$. As in the deaf group, age and reading score are significantly correlated in the hearing group, $r = 0.618$, $p = 0.001$. As expected, in both groups, weaker readers are younger and better readers are older. We

Table 1: Subject grouping

Age group/ subjects	Group 1 (10–12 years old)		Group 2 (13–15 years old)		Group 3 (16–18 years old)	
	Age	Reading score (%)	Age	Reading score (%)	Age	Reading score (%)
Deaf						
Mean	11.54	56.53	14.65	78.96	16.93	84.50
(SD)	(0.82)	(8.17)	(0.94)	(9.45)	(0.83)	(8.63)
Hearing						
Mean	11.23	80.98	14.22	96.19	16.88	95.72
(SD)	(0.73)	(29.30)	(0.91)	(2.29)	(1.03)	(3.12)

therefore considered only age in the analyses presented below. See Table 1 for subjects' details.

Materials[3]

The materials were composed of 60 pairs of pseudo-words grouped into two experimental conditions: position and vowel. In all cases, the experimental items are pseudo-words (see Appendix 1). All pseudo-words are six letters long and, within a given pair, share the same number of syllables.

In the position condition, 30 pairs of items assess knowledge about the legal position of double consonants. In all cases, the double consonants compared are part of the same frequency group. Half of the pairs compare items with a double consonant in the legal position with a double consonant in an illegal position at the beginning of the item (*tunnir* vs. *ttunir*) and half with a double consonant in an illegal position at the end of the item (*ruttan* vs. *rutann*). In 10 pairs, frequent double consonants are involved (*fellut* vs. *felutt*). In 10 pairs, items are built with less frequent double consonants (*bippoc* vs. *bipocc*). The last 10 pairs include double consonants that cannot be doubled (*levvuw* vs. *levuww*). These last pairs seek to assess whether subjects use their visuo-orthographic knowledge at a more abstract level. In other words, if they know that consonants are in median position in words, can they apply that knowledge to double consonants that do not exist in written French (as in Pacton *et al*., 2001)?

Lastly, in the vowel condition, 30 pairs of pseudo-words assess the fact that consonants are doubled much more often than vowels. In 10 pairs, double vowels are opposed to frequent double consonants (*rallar* — *raalar*). In 10 other pairs, double vowels are compared to less frequent double consonants (*laffir* — *laafir*). The last 10 pairs involved double vowels and double consonants that do not exist in written French (*ravvul* — *raavul*).

In addition to the general expectations cited above in relation to the potential effect of position and to the potential effect of frequency observable by differences in scores according to age and to the frequency of double consonants, we formulated the following specific expectations from the materials should the subjects manifest visuo-orthographic knowledge:

For the items in the position condition:

- Success rates should be higher when the unexpected answer involving a double consonant is in the initial position than in the final position.
- Success rates should be higher for older subjects than younger subjects, and success rates should be higher for pairs involving frequent double consonants than for pairs with less frequent double consonants, which should themselves be higher than success rates for consonants that cannot be doubled. Moreover, if subjects use their visuo-orthographic knowledge at an abstract level, success rates for pairs involving consonants that cannot be doubled should be higher than chance.

For the items in the vowel condition:

- Success rates should be higher for older subjects than younger subjects, and success rates should be higher for pairs involving frequent double consonants than for pairs of less frequent double consonants, which should themselves be higher than success rates for consonants that cannot be doubled. Moreover, if subjects use their visuo-orthographic knowledge at an abstract level, success rates for pairs involving consonants that cannot be doubled should be higher than chance.

Procedures

We used the LEA software (Bastien, 2002) to create the experimental tasks and gather the success rate scores. Sessions were conducted individually in a quiet room on a portable PC computer. A deaf research assistant and a hearing research assistant, both trained for this experiment, gave instructions in Quebec Sign Language and in French respectively, according to subjects' hearing status. The subjects were told that they would see two pseudo-words on the screen. They were asked to determine which of the two items most resembled a real word in written French. To answer, they had to press one of two predefined keys on the keyboard.

The items were presented randomly. Pairs of items always appeared the same way. The items showed up simultaneously, one on the left and one on the right, in the middle of the screen. The position of the expected answer was defined randomly. Items stayed on the screen until subjects answered or for a maximum of 10,000 ms. A series of Xs then appeared and stayed for 1,000 ms, followed by another pair of items. The experimental material was grouped in blocks of 10 pairs and an unlimited pause was planned between each block. The subjects controlled the length of the pause by pressing the spacebar. The test started with 10 practice pairs followed by the experimental pairs.

The statistical procedures were as follows. First, because answers were always binary, we investigated whether the results were due to chance, i.e., 50% on average, with a Student t-test. Second, we conducted an analysis of variance (ANOVA) with two between-subjects factors, one factor *Age group* with three levels (10–12 years old, 13–15 years old and 16–18 years old) and one factor *Hearing status* with two levels (deaf or hearing), followed, if necessary, by a Tukey contrast analysis for age group. In the event of significant interaction between factors, local analyses were planned. Third, in order to verify the effect of the experimental material on success rates, ANOVAs were conducted with the criteria used for constructing the experimental materials as within-subjects factors (position of double consonant and frequency of double consonant).

Results

Results in the position condition

Analysis of success rate

First, we determined whether the scores obtained by subjects were different from chance (50%). As we can observe in Table 2, for all groups, the general results are significantly different from the chance level.

Table 2: Mean scores (%, SD) in the position condition

Age group/ subjects	Group 1 (10–12 years old)	Group 2 (13–15 years old)	Group 3 (16–18 years old)
Deaf			
Mean scores (SD)	62.5 (9.72)	84.58 (8.15)	83.75 (9.67)
Chance	$t(7) = 3.64$, $p = 0.008$	$t(7) = 12$, $p < 0.001$	$t(7) = 9.87$, $p < 0.001$
Hearing			
Mean scores (SD)	89.85 (7.57)	93.53 (5.6)	93.96 (7.56)
Chance	$t(7) = 14.88$, $p < 0.001$	$t(7) = 22$, $p < 0.001$	$t(7) = 16.45$, $p < 0.001$

For the analysis of total scores in the position condition, we used a 2×3 ANOVA, with hearing status (deaf, hearing) and age group (1, 2, 3) as between-subjects factors. The results showed an effect of hearing status, F (1,42) = 43.229, $p < 0.001$, $\eta_p^2 = 0.507$, an effect of age group, F (2,42) = 13.061, $p < 0.001$, $\eta_p^2 = 0.383$, and significant interaction between both variables, F (2,42)

= 6.337, p = 0.004, η_p^2 = 0.232. For each age group, deaf subjects obtained lower scores than the hearing subjects. Moreover, a post hoc analysis (Tukey) revealed that deaf readers aged 10–12 obtained lower scores than subjects aged 13–15 ($p < 0.001$) and subjects aged 16–18 ($p < 0,001$). The results for the two older groups did not differ (p = 0.982). In contrast, hearing subjects did not differ according to age groups, F (2,21) < 1, ns).

In brief, deaf subjects obtained lower scores than age-matched hearing subjects. While in deaf subjects scores increased as subjects increased in age, in hearing subjects scores are not significantly different according to age group.

Analysis of scores according to the position of the illegal double consonant

We were also interested to know whether scores differed according to the position of the double consonant in the unexpected answer. The scores are presented in Table 3.

Table 3: Mean scores (%, SD) in the position condition, according to the position of the illegal double consonant

Age group/ subjects	Group 1 (10–12 years old)	Group 2 (13–15 years old)	Group 3 (16–18 years old)
Deaf — initial[a]			
Mean score (SD)	70.83 (14.67)	90.83 (4.96)	96.67 (5.04)
Chance	t(7)=4.02, p=0.005	t(7)=23.30, p<0.001	t(7)=26.19, p<0.001
Deaf — final[b]			
Mean score (SD)	54.17 (16.5)	78.33 (12.21)	71.67 (16)
Chance	t(7)=0.71, ns	t(7)=6.56, p<0.001	t(7)=3.61, p=0.009
Hearing — initial[a]			
Mean score (SD)	94.18 (8.3)	94.17 (7.5)	97.29 (3.78)
Chance	t(7)=15.05, p<0.001	t(7)=16.65, p<0.001	t(7)=35.42, p<0.001
Hearing — final[b]			
Mean score (SD)	85.01 (11.12)	93.33 (6.17)	89.99 (12.36)
Chance	t(7)=8.91, p<0.001	t(7)=19.86, p<0.001	t(7)=9.15, p<0.001

[a] initial (ttunir)
[b] final (felutt)

As mentioned above, unexpected answers involved a double consonant either at the initial (*ttunir*) or at the end of the items (*felutt*). For 10–12-year-old deaf subjects, results were significantly different from chance when the unexpected answer involved a double consonant in the initial position but were not different from chance when the unexpected answer included a double consonant in the final position. All other results cannot be accounted for by chance.

The ANOVA with hearing status and age group as between-subjects factors and position of the double consonant in the unexpected answer as a within-subjects factor only showed a position effect, F (1,42) = 32.994, $p < 0.001$, $\eta_p^2 = 0.440$, and an interaction between the position of the double consonant and hearing status, F (1,42) = 8.777, $p = 0.005$, $\eta_p^2 = 0.173$. All other effects were not significant. In all age groups, deaf and hearing subjects obtained better scores when the unexpected answer involved a double consonant at the beginning of the item than at the end. However, this difference was greater in deaf subjects (86.11%–68.05%) than in hearing subjects (95.21%–89.44%). Moreover, when double consonants were in an initial position in the unexpected answer, only deaf subjects aged 10–12 obtained lower scores than matched hearing subjects ($p = 0.002$). For 13–15- and 16–18-year-old subjects, deaf readers' scores did not differ from those of hearing readers. In contrast, when double consonants were in final position, deaf subjects, regardless of age group, obtained lower scores than hearing subjects ($p < 0.001$).

Analysis of scores according to the frequency of the double consonant

Lastly, we investigated the effect of the frequency of double consonants. For example, in the initial position, items could include a frequent double consonant (*ttunir*), a less frequent double consonant (*ffamir*) or a consonant that cannot be doubled in French (*xxovir*). The results according to the frequency of double consonants are presented in Table 4.

Analysis of success rate according to chance level indicated that almost all results are significantly different from chance. Only 10–12-year-old deaf subjects responded at chance in pairs of items involving a less frequent double consonant. We conducted an ANOVA with frequency of double consonants (frequent, less frequent or cannot be doubled) as a within-subjects factor and age group and hearing status as between-subjects factors. The ANOVA revealed a significant effect for the frequency of consonants, F (2,84) = 31.135, $p < 0.001$, $\eta_p^2 = 0.426$, but no interaction between hearing status and the frequency of consonants, F (2,84) = 1.558, *ns*, $\eta_p^2 = 0.036$, and no interaction between age group and the frequency of consonants, F (4,84) = 0.907, *ns*, $\eta_p^2 = 0.041$. A post hoc analysis showed that, in deaf and in hearing subjects, scores on items including a consonant that cannot be doubled were lower than on items with frequent or less frequent double consonants (in both cases, $p < 0.001$). Results on items with frequent or less frequent double consonants did not differ significantly ($p = 0.825$).

Table 4: Mean scores (%, SD) in the position condition, according to the frequency of the double consonant

Age group/ subjects	Group 1 (10–12 years old)	Group 2 (13–15 years old)	Group 3 (16–18 years old)
Deaf — frequent[a]			
Mean score (SD)	67.5 (20.53)	93.75 (7.44)	96.25 (5.18)
Chance	$t(7)=2.41$, $p=0.047$	$t(7)=16.63$, $p<0.001$	$t(7)=25.28$, $p<0.001$
Deaf — less frequent[b]			
Mean score (SD)	61.25 (17.27)	92.5 (8.86)	88.75 (15.53)
Chance	$t(7)=1.84$, ns	$t(7)=13.56$, $p<0.001$	$t(7)=7.06$, $p<0.001$
Deaf — cannot be doubled[c]			
Mean score (SD)	58.75 (8.35)	67.5 (17.52)	66.25 (14.08)
Chance	$t(7)=2.97$, $p=0.021$	$t(7)=2.82$, $p=0.026$	$t(7)=3.27$, $p=0.014$
Hearing — frequent[a]			
Mean score (SD)	96.25 (7.44)	96.25 (7.44)	97.5 (4.63)
Chance	$t(7)=17.58$, $p<0.001$	$t(7)=17.58$, $p<0.001$	$t(7)=9.15$, $p<0.001$
Hearing — less frequent[b]			
Mean score (SD)	95 (7.56)	97.5 (7.07)	100 (0)
Chance	$t(7)=16.84$, $p<0.001$	$t(7)=19$, $p<0.001$	—[4]
Hearing — cannot be doubled[c]			
Mean score (SD)	78.75 (19.59)	86.25 (14.08)	85 (19.27)
Chance	$t(7)=4.15$, $p=0.004$	$t(7)=7.28$, $p<0.001$	$t(7)=5.14$, $p=0.001$

[a] frequent (ttunir)
[b] less frequent (ffamir)
[c] cannot be doubled (xxovir)

Results in the vowel condition

Analysis of success rate

First, we determined whether scores obtained by subjects were different from chance (50%). As we can observe in Table 5, for all groups, except for deaf subjects aged 10–12, the results were significantly different from the chance level.

For the analysis of total scores in the vowel condition, we used a 2 × 3 ANOVA, with hearing status (deaf, hearing) and age group (1, 2, 3) as between-subjects factors. Results showed an effect for hearing status, $F\ (1{,}42) = 38.749$,

Table 5: Mean scores (%, SD) in the vowel condition

Age group/ subjects	Group 1 (10–12 years old)	Group 2 (13–15 years old)	Group 3 (16–18 years old)
Deaf			
Mean scores (SD)	58.34 (12.6)	85.41 (9.07)	84.17 (5.84)
Chance	$t(7)=1.87$, ns	$t(7)=11.04$, $p<0.001$	$t(7)=16.55$, $p<0.001$
Hearing			
Mean score (SD)	90.84 (7.72)	91.58 (5.94)	92.01 (8.75)
Chance	$t(7)=14.97$, $p<0.001$	$t(7)=19.78$, $p<0.001$	$t(7)=13.57$, $p<0.001$

$p < 0.001$, $\eta_p^2 = 0.480$, an effect for age group, $F\ (2,42) = 13.461$, $p < 0.001$, $\eta_p^2 = 0.391$, and significant interaction between both variables, $F\ (2,42) = 11.687$, $p < 0.001$, $\eta_p^2 = 0.358$. A post hoc analysis (Tukey) showed that 10–12-year-old deaf subjects obtained lower scores than 13–15- and 16–18-year-old subjects (in both cases, $p < 0.001$). No difference was found between the two older deaf groups ($p = 0.963$). In contrast, no difference was found between age groups in hearing subjects. Moreover, 10–12-year-old deaf subjects obtained lower scores than hearing controls ($p < 0.001$), but no significant difference was found between deaf and hearing subjects in the two older groups.

In sum, deaf subjects obtained lower scores than hearing subjects only in the younger group. In deaf subjects, the score increased with age. In hearing subjects, scores did not differ significantly from one age group to another.

Analysis of scores according to the frequency of the double consonant

Lastly, we investigated the effect of the frequency of double consonants when subjects had to choose between a double vowel and a double consonant (see Table 6).

Double vowels were compared to frequent double consonants (*rallar* — *raalar*), less frequent double consonants (*laffir* — *laafir*), or to consonants that cannot be doubled in French (*ravvul* — *raavul*). For hearing subjects, all results are significantly different from the chance level. For deaf subjects, results are different from chance when double vowels were compared to frequent double consonants. When double vowels were compared to less frequent double consonants, the results were different from chance only for 13–15- and 16–18-year-old subjects. Finally, when double vowels were compared to consonants that cannot be doubled, 13–15- and 16–18-year-old deaf subjects' results were not different from chance. For the youngest deaf group, the results were different from chance when double vowels were compared to consonants that cannot be doubled. However, in this case, subjects selected the

Table 6: Success rate (%) in the vowel condition, according to the frequency of the double consonant

Age group/ subjects	Group 1 (10–12 years old)	Group 2 (13–15 years old)	Group 3 (16–18 years old)
Deaf — frequent[a]			
Mean score (SD)	82.5 (15.81)	96.25 (5.18)	98.75 (3.53)
Chance	$t(7)$=5.81, p=0.001	$t(7)$=25.28, $p<0.001$	$t(7)$=39, $p<0.001$
Deaf — less frequent[b]			
Mean score (SD)	66.25 (23.26)	97.5 (4.63)	98.75 (3.53)
Chance	$t(7)$=1.98, ns	$t(7)$=29.02, $p<0.001$	$t(7)$=39, $p<0.001$
Deaf — cannot be doubled[c]			
Mean score (SD)	26.25 (20.66)	62.5 (25.5)	55 (15.12)
Chance	$t(7)$=-3.25, p=0.014	$t(7)$=1.39, ns	$t(7)$=0.94, ns
Hearing — Frequent[a]			
Mean score (SD)	100 (0)	100 (0)	100 (0)
Chance	—	—	—
Hearing — Less frequent[b]			
Mean score (SD)	95 (10.69)	98.75 (3.54)	98.75 (3.54)
Chance	$t(7)$=11.91, $p<0.001$	$t(7)$=39, $p<0.001$	$t(7)$=39, $p<0.001$
Hearing — cannot be doubled[c]			
Mean score (SD)	77.5 (14.88)	75 (17.73)	77.5 (26.05)
Chance	$t(7)$=5.28, p=0.001	$t(7)$=3.99, p=0.005	$t(7)$=2.99, p=0.02

[a] frequent (rallar — raalar)
[b] less frequent (laffir — laafir)
[c] cannot be doubled (ravvul — raavul)

unexpected answer more systematically (i.e., they selected the item with a double vowel).

We conducted an ANOVA with frequency of double consonants (frequent, less frequent or cannot be doubled) as a within-subjects factor as well as age group and hearing status as between-subjects factors. A consonant frequency effect was revealed, F (2,84) = 91.667, $p < 0.001$, $\eta_p^2 = 0.686$, as well as an interaction between consonant frequency and hearing status, F (2,84) = 8.921, $p < 0.001$, $\eta_p^2 = 0.175$. All other effects were not significant.

In deaf subjects, when double vowels were compared to frequent double consonants, scores were higher than when they were compared to less frequent double consonants ($p = 0.024$) or consonants that cannot be doubled ($p < 0.001$). Double vowels compared to less frequent consonants also caused fewer errors than when they were compared to consonants that cannot be doubled ($p < 001$). In hearing subjects, scores did not differ when double vowels were compared to frequent or to less frequent double consonants ($p = 0.26$). However, when vowels were compared to consonants that cannot be doubled, scores were lower than when they were compared to frequent or less frequent double consonants ($p < 0.001$ in both cases).

Discussion

The purpose of this study was to investigate visuo-orthographic knowledge in deaf readers of different ages. This type of knowledge participates in orthographic processing in word recognition and is of interest since it does not involve phonology, which causes important difficulties in deaf readers (Musselman, 2000). The specific visuo-orthographic knowledge involved in the task used in this study is not taught explicitly in class. Its acquisition is believed to be the result of implicit learning related to the frequency of print exposure (Gombert, 2003). Two main effects were expected to illustrate subjects' sensitivity to visuo-orthographic knowledge. First, considering the work of Padden (1993), we expected a position effect where orthographic representations would be better defined for the beginning of items than for the end of items. Second, we expected a frequency effect observable by a difference in scores according to age group (16–18 years old > 13–15 years old > 10–12 years old) and, for a specific age group, a difference in scores according to the frequency of letter patterns (frequent double consonants > less frequent double consonants > cannot be doubled consonants).

The discussion that follows concerns, first, the effect of the position of double consonants in written items and, then, the effect of frequency observable by a difference in scores according to age group and according to the frequency of double consonants.

According to our first general expectation, we anticipated higher success rates when the unexpected answer involved a double consonant in the initial position (*ttunir*) than in the final position (*felutt*). This expectation was based on Padden (1993) who had shown that deaf students develop better representations for the beginning of words than for the end of words. Only results in the position condition were used to verify this expectation. According to these results, we can say that in general our subjects have developed some visuo-orthographic knowledge in relation to the legal position of double consonants in written items. Indeed, deaf and hearing subjects prefer items with a double consonant in the median position (legal) than with a double consonant at the beginning or the end position (illegal). This is in line with the observation of the respect for orthographic legality made in hearing readers of English (Cassar and Treiman, 1997; Hagiliassis *et al*., 2006), in hearing readers of French (Pacton *et al*., 2001), and in deaf readers of English (Harris and Moreno, 2004). More specifically, in accordance with our first general expectation, this study also shows that deaf readers and hearing readers have better orthographic representations for the beginning of words than the end of words. Of interest is the fact that when the double consonant is in the initial position (in the unexpected answer), deaf readers reach the level of performance of hearing readers in age groups 2 and 3. However, when the double consonant is at the end of written items, deaf subjects' results fall behind those of hearing readers, whatever the age group. These findings are in line with Padden (1993), who showed that deaf readers develop orthographic knowledge related to the beginning of words earlier than knowledge related to the end of words. It has been suggested that deaf readers often guess the meaning of words on the basis of the first letters (Paul, 1998). Our findings may be representative of such a reading strategy where deaf readers pay specific attention to the beginning of words, which would favor the development of specific orthographic representation for the beginning but not for the end of words.

The second general expectation in relation to the potential effect of frequency on success rates was thought to emerge from the observation of two specific effects: age and double consonant frequency. The results in both experimental conditions were used to verify this expectation. Both Gombert (2003) and Pacton *et al*. (2001) consider that some regularities related to the orthographic system (like those targeted in this study) are acquired through experience with print. In this respect and in the context of our study, older readers should develop better orthographic representations in relation to visuo-orthographic knowledge than younger readers. In the position condition and in the vowel condition, the general results indicated 10-12-year-old deaf subjects obtained lower scores than subjects from the two older deaf groups. In contrast, no age difference was found in hearing subjects. Instead of considering these results as contradicting the expected frequency effect, we believe that they are a consequence of well-acquired visuo-orthographic knowledge, in the hearing subjects at least. Indeed, the very high scores in hearing readers observed already in the first age group may not have allowed the emergence of the expected effect. This is in line with Pacton *et al*. (2001) whose results indicated a difference between hearing first and second graders, but no difference after the second grade. This indicates that the targeted visuo-orthographic knowledge may exist in the early stages of reading acquisition. However, in deaf readers, our results show that this type of knowledge is acquired later than in hearing readers. Deaf subjects continue to acquire visuo-orthographic knowledge after primary school, where that knowledge seems to have been already acquired by hearing readers.

The frequency effect was also expected to be revealed by a difference in scores according to the frequency of double consonants. Indeed, if as Gombert (2003) argues, frequency is the driver of implicit learning, we can assume that results will be related to the frequency of double consonants involved in the experimental items. We therefore formulated a specific expectation according to which the success rate should be higher for pairs involving frequent double consonants than for pairs of less frequent double consonants, which should itself be higher than the success rate for consonants that cannot be doubled. In the position condition, in both populations, items including consonants that cannot be doubled created more errors than items involving possible double consonants. However, no difference was found between items with frequent or less frequent double consonants. In the vowel condition, the results were similar for hearing readers. When doubled vowels were compared to possible double consonants (frequent or less frequent), scores were higher than when vowels were compared to consonants that cannot be doubled. However, in deaf subjects, success rates decreased, as expected, as the frequency of double consonants became lower (frequent double consonants > less frequent double consonants > consonants that cannot be doubled). In deaf subjects, these results are in accordance with Gombert (2003). More frequent double consonants are better represented than less frequent double consonants. In hearing readers, very high scores in the latter two types of items can account for the absence of difference. While our expectation was not met in hearing readers, it does not necessarily mean that frequency does not explain the acquisition of this specific visuo-orthographic knowledge. Our results may instead be representative of already well-established knowledge. Indeed, Pacton *et al.* (2001) showed that even first graders were sensitive to the frequency of double consonants. In comparison with hearing subjects, our results would also mean that deaf subjects are still in the process of acquiring visuo-orthographic knowledge, even after years of exposure to written language.

Of particular interest are our findings related to items involving consonants that cannot be doubled. Pacton *et al.* (2001) found that hearing readers of French use their visuo-orthographic knowledge to process items built with double consonants that do not exist in the written language. As in Pacton's study, our results in hearing readers also show the use of this specific knowledge. This is the case for both conditions. Even if results are lower when related to items with consonants that cannot be doubled compared to possible double consonants, they are different from what would be expected by chance. In other words, hearing subjects know that double consonants are legal only in the median position and that double consonants are more probable than double vowels, and they apply this knowledge to items built with consonants that cannot be doubled. In our deaf subjects, however, the situation is different. In the position condition, the difference in scores between possible and impossible double consonants was much greater. In fact, deaf subjects from the first age group responded randomly or close to chance, depending on double consonant frequency. In the vowel condition, deaf subjects aged 10-12 prefered a double vowel to a double consonant (the opposite of the expected pattern) and older deaf subjects responded randomly. This seems to illustrate a difficulty in reorganizing visuo-orthographic knowledge at an abstract level. In other words, hearing readers' results can be interpreted in terms of rule formulation: double consonants, whether they are possible or not in French, are in the median position and double consonants are more probable than double vowels. Deaf subjects' visuo-orthographic knowledge does not seem to be as regulated. These findings suggest that frequency alone (defined according to the potential effects of age and of letter frequency) cannot explain everything we observed in deaf readers. It seems that preferred reading strategies (as illustrated in the position condition) and the capacity of reorganizing visuo-orthographic knowledge may also be factors to be considered.

In brief, this study has shown that deaf readers develop some visuo-orthographic knowledge that is not dictated by phonology, as it has been argued. This is of interest in light of the difficulties deaf readers experience in processing phonology (Musselman, 2000). In order to meet our objective, we used a word-likeness choice task for the first time with deaf readers of French. This task was shown to be appropriate for studying visuo-orthographic knowledge in our population, and results in hearing subjects are congruent with those of past studies that used a similar task (Cassar and Treiman, 1997; Pacton *et al.*, 2001; Hagiliassis *et al.*, 2006). However, our study indicates that deaf readers are not as competent as hearing readers in using their visuo-orthographic knowledge. It could be argued that deaf readers read less than hearing readers and as such do not acquire as much visuo-orthographic knowledge compared to hearing readers. Indeed, if we assume that frequency of contact with orthographic structures implicitly drives the constitution of representations associated with such visuo-orthographic structures as others have suggested (Pacton *et al.*, 2001; Gombert, 2003), our results suggest that other processes may also guide the acquisition of visuo-orthographic knowledge. Our results point to two alternative explanations. First, preferred strategies used by readers may influence the acquisition of such structures. This may explain the difference we found between hearing and deaf readers in relation to the position of targeted letter sequences. Second, more general cognitive processes may also influence the acquisition of visuo-orthographic knowledge. As we have seen, in contrast to hearing readers, deaf readers do not seem to reorganize their knowledge in order to deal with abstract situations related to orthographic structures. More specifically, the deaf readers in this study knew that doubled letters occur in median position in written items and knew that consonants are doubled much more often than vowels. However, when they had to apply that knowledge to orthographic structures involving consonants that cannot be doubled, they responded randomly. This difference between hearing and deaf readers may indicate that the difficulty deaf students have in learning to read does not only concern phonological processing. Orthographical processing may also be a source of problems for deaf readers. Another explanation involves the learning environment in which deaf students acquire reading and, more specifically, in which they implicitly acquire visuo-orthographic knowledge. Activities in which implicit learning occurs must be meaningful. If this comment is self-evident for most readers, it cannot be taken for granted with deaf readers. Indeed, it is difficult for some deaf students, like those who participated in this study, who use sign language as their main medium of communication to find meaning in texts or, at times, to understand why reading is important. For them, the majority language can be considered a second language. However, reading instruction often does not take this situation into account, and reading instructors do not always provide meaning through sign language. As a result, some deaf students do not know why they read or what they read. In this context, it seems reasonable to believe that learning is considerably impeded.

Conclusion

This study has shown that deaf subjects demonstrate some visuo-orthographic knowledge. Since the knowledge assessed in this study is not taught, we believe it arises from implicit learning processes activated for the most part through contact with print. Even if frequency is in all likelihood a driver of implicit learning, other factors may be at work in implicit learning processes. Research on deaf readers needs to be pursued and promoted not only to help understand how deaf readers read and learn to read, but also because research with exceptional populations contributes significantly to the general understanding of reading acquisition.

Notes

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[1] There is still a debate in deaf education concerning the potential benefits of one approach over another. Two families of educational approaches guide school practices: oral approaches and manual approaches. Tenants of oral approaches believe that learning to read and write is done through mastery of the oral language whereas tenants of manual approaches feel that sign languages or manual codes are essential for reading/writing acquisition (for a discussion, see Marschark *et al.*, 2002, and Moores and Martin, 2006).

[2] The reading comprehension test was created with the Zigzag technique developed by Ciesielski and Reinwein (1989) and used in many different studies as an experimental measure or as a control measure, as in the present case (Bastien, 1997; see also `www.unites.uqam.ca/zigzag`). The Zigzag technique consists of a reading activity activated by a segment-by-segment autopresentation of the text to be constructed by the reader. The readers always have the choice between two items — an expected item and a distracter — and must select the expected one in order to activate the following part of the text. The anterior context then appears in a window on the computer. For this study, subjects had to read three texts of about 100 words each. The first one was a practice text. We used the average success rate of the two experimental texts as the reading score for each subject.

[3] In order to create the experimental items, we first determined which consonants are never doubled and then the frequency of single consonants, double consonants and double vowels using the electronic version of *Le Petit Robert* (Robert, 1995). The consonants that are never doubled are J, Q, C, W and X. We kept J, V, W and X, and eliminated Q since it always appears in words followed by U. Among frequent consonants that can be doubled, L, S, N and T are doubled frequently (on average 23,158 entries in the dictionary when not doubled and 2,092 when doubled) and C, F, M and P are less frequently doubled (on average, 14, 417 entries in the dictionary when not doubled and 535 entries when doubled). In fact, the most frequent double consonants also constitute the most frequent single consonants. However, we felt that since the difference is 2.5 greater in the case of double consonants compared to single consonants, the material should make it possible to distinguish between sensitivity to double consonants compared to single consonants, which would not have been possible if the difference between averages had been nil. Lastly, in contrast to Pacton *et al*. (2001), we observed that vowels can sometimes be doubled. For example, O is doubled is the word *zoo*. Vowels can also be doubled in verbs when they are conjugated in the imperfect indicative (*nous étudiions* — we were learning), and E is often doubled in past participles (*donnée* — given), etc. In general, however, compared to consonants, vowels are rarely doubled. Following Pacton *et al*. (2001), we consider double vowels more illegal than double consonants.

[4] Considering that all subjects in this subgroup achieved 100%, a *t*-test analysis was not possible. This will also be the case for results in the vowel condition (see Table 6). However, the results are obviously different from chance.

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Appendix:
Experimental materials

Condition: position					
FVFFVC	FFVFVC	CVFFVF	CVFVFF	RVRRVC	RRVRVC
lannoc	llanoc	ballis	baliss	fammir	ffamir
sottup	ssotup	ruttan	rutann	piccor	ppicor
nillor	nnilor	cennol	cenoll	muppal	mmupal
tunnir	ttunir	fellut	felutt	caffur	ccafur
sillap	ssilap	dinnus	dinuss	fippel	ffipel
CVRRVR	CVRVRR	NVNNVC	NNVNVC	CVNNVN	CVNVNN
daffim	dafimm	vajjer	vvajer	lejjav	lejavv
bippoc	bipocc	waxxel	wwaxel	sawwix	sawixx
gaccaf	gacaff	xovvir	xxovir	moxxaj	moxajj
rommip	romipp	jiwwal	jjiwal	levvuw	levuww
sappum	sapumm	voxxet	vvoxet	bojjax	bojaxx

Condition: vowel					
CVFFVC	CVVFVC	CVFFVC	CVFVVC	CVRRVC	CVVRVC
rallar	raalar	mallit	maliit	laffir	laafir
pinnet	piinet	bennel	beneel	bemmot	beemot
bottur	bootur	tillar	tilaar	nippul	niipul
meller	meeler	sattor	satoor	soccar	soocar
junnat	juunat	dannul	danuul	tuffer	tuufer
CVRRVC	CVRVVC	CVNNVC	CVVNVC	CVNNVC	CVNVVC
beppar	bepaar	ravvul	raavul	dowwal	dowaal
toccel	toceel	bejjar	beejar	baxxer	baxeer
ruffir	rufiir	siwwer	siiwer	tuvvis	tuviis
gommot	gomoot	poxxel	pooxel	rejjot	rejoot
feppul	fepuul	ruvvor	ruuvor	miwwur	miwuur

C = non targeted consonant
V = vowel
F = frequent single consonant used in frequent double consonant
R = frequent single consonant used in less frequent double consonant
N = consonant that cannot be doubled