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Phonological decoding in severely and profoundly deaf children: Similarity judgment between written pseudowords

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ABSTRACT
This study attempted to determine whether phonological decoding could be observed among severely and profoundly deaf children during reading. For this purpose, the ability of 20 deaf children to detect phonological similarities between three written pseudowords (a model item and two test items) was investigated. In the first condition, one of the test items was a homophone of the model (e.g., ***kise***, *kyse*, *kine*). In the second condition, one of the test items had the same first syllable as the model item, as defined by its structure or by nasalization (e.g., ***lan.jier***, *lan.du*, *la.nud*). The results demonstrated that deaf children with good speech levels, as well as hearing children matched on word reading level, were sensitive to homophony when visual proximity between the model and test items were controlled. They were also sensitive to syllabic structure when the first syllables were CV and in the nasalization condition. By contrast, deaf children with poor speech abilities did not show this pattern of results in all conditions. The possibility that the latter results could be explained by deaf children's sensitivity to orthographic frequency phenomena is discussed. A link between sensitivity to phonology in written language and speech skills is suggested, and the implications of those results for a general understanding of the reading processes of deaf children are presented.

For beginning readers, the decoding mechanism, consisting of applying correspondences between visuo-orthographic forms and phonological forms, represents a key step in literacy development (Ehri, 1998; Frith, 1985; Goswami & Bryant, 1990). When children possess some mastering of decoding skills at the grapho-phonemic level, they develop the use of infralexical reading units that are larger than graphemes (Duncan, Seymour, & Hill, 1997; Ehri & Robbins, 1992; Seymour, Duncan, & Bolik, 1999; Seymour & Evans, 1994). The automatization of this process enables children to develop their reading abilities up to an expert reading level. However, the attainment of good decoding skills depends on the preliminary development of accurate phonological representations (Duncan, Seymour, & Hill, in press; Gombert & Colé, 1999). This developmental process is greatly compromised in severely and profoundly deaf children because of the absence of numerous, precise, and redundant oral language inputs. Thus, our aim is to determine the existence (and the conditions of existence) of decoding processes during silent reading in deaf children.

Before tackling the question of reading processes among deaf children, it may be worthwhile to note that phonological development is not exclusively dependent on the auditory modality because phonological representations do not correspond to surface features of speech. Phonological representations are of an abstract nature, representing the "meaningless primitives out of which meaningful units are formed" (Hanson, 1989, p. 73). Recent studies support the hypothesis that phonological segmental information could be obtained by deaf people through sensorial modalities other than audition. One main source of information that enables the emergence of phonological representations in deaf children is speech reading (Campbell, 1997; Dodd, 1976). Nevertheless, phonological information contained in visual speech reading is poorer, scarcer, and less precise than information based on auditory inputs for hearing people because many phonemes have similar labial images or no labial correlates. As an example, the bilabial consonants /p/, /b/, and /m/ have almost the same labial images, and the velar consonants /k/ and /g/ are not readily visible.

Speech articulation abilities also play a role in the constitution and use of phonological representations. Deaf people with good speech intelligibility (which is often associated with good residual hearing) show stronger phonological coding effects during short-term memory tasks involving written material than do deaf people with lower speech intelligibility (Conrad, 1979). But, in general, phonological representations of severely and profoundly deaf people are described as poorer and less precise than those of hearing people. One could mention some exceptional cases of rich phonological development among profoundly deaf people who were early and intensively exposed to Cued Speech, a visuomanual method of speech reading completion. However, those deaf children constitute a minority among the deaf community (see reviews in LaSasso & Metzger, 1998; Leybaert, 1998; Leybaert, Alegria, Hage, & Charlier, 1998).

The question as to whether phonological codes may be activated during reading has been investigated using different experimental paradigms (see reviews in Leybaert, 1993; Marschark, 1993). Evidence of phonological activation has often been found in tasks where oral responses were required. Leybaert (1993) observed fewer pronunciation errors in the reading of easy pseudowords containing one-letter-to-one-phoneme correspondences than in the reading of complex pseudowords containing several-letters-to-one-phoneme correspondences or context-dependent correspondences. This result was interpreted as suggesting that deaf people may be able to use grapheme–phoneme correspondence processes in reading pseudowords.

In experiments not requiring an oral response, evidence for grapho-phonological conversion was rarely observed. Leybaert and Alegria (1993) investigated phonological assembly processes in deaf children (mean age = 13;3) in a Stroop task. In this task, participants were asked to name the color of an item. When this item was the name of another color (e.g., VERT, green, written in red ink) there was an interference effect, which was interpreted as arising from an automatic activation of the word's phonological representation. In the case of pseudowords that were homophones of color names (e.g., French-speaking children were asked to name the color of the pseudoword VAIRE_GREAN, homophone of *vert*, green), an interference effect evidenced automatic activity of the assembly process, which led to the activation of the color word's phonological representation. Leybaert and Alegria (1993) found a larger interference effect from homophone pseudowords than nonhomophone pseudowords matched for orthographic similarity vis-à-vis the color word (e.g., VOURE) in deaf children when responses were given orally but not when responses were given manually. In a control group of hearing children, the interference effects created by the homophonic pseudowords were significant in both response modalities.

In a lexical decision paradigm in which participants used a manual response to identify items as words, significant regularity effects were observed in hearing groups, but no indication of phonological coding was found in deaf populations matched on reading level (Burden & Campbell, 1994; Merrills, Underwood, & Wood, 1994; Waters & Doehring, 1990).

By contrast, some strong evidence in support of phonological activation during silent reading in deaf people was provided by the observation of pronounceability effects in a letter detection task and by regularity effects found in lexical decision tasks by Hanson (1986) and Hanson and Fowler (1987). However, those populations consisted of deaf high school students. This limited the generalization of any conclusions concerning the reading strategies of most deaf people, among whom the mean grade level of school dropouts is the equivalent of the third or fourth grade (Conrad, 1979; Paul & Quigley, 1994).

There is only one piece of evidence that supports the existence of phonological coding in the silent reading of isolated items by young deaf children. In a lexical decision task with no time limit, frequent words and pseudowords were presented on cards to young deaf children (mean age = 9;9) and hearing children (mean age = 7;3). Deaf children with good speech abilities found it more difficult to reject pseudohomophones that were visually similar to frequent words (e.g., pseudoword *somo* vs. source word *some*) than control pseudowords matched in letter length and in similarity and frequency to source words (Beech & Harris, 1997). This result indicates that, in reading pseudowords, deaf children with good speech used phonological decoding processes. These children may have developed phonological representations that were precise enough to be used during the reading activity. This result was important as the use of the phonological decoding by deaf people may be correlated with more general abilities implicated in reading, such as vocabulary or comprehension (Conrad, 1979; Harris & Beech, 1998).

Despite these advances, our knowledge as to the way phonological decoding occurs in deaf children during silent reading is far from complete. In particular, Beech and Harris's (1997) study did not systematically examine deaf children's abilities to associate reading units with phonological units as a function of their speech abilities and their hearing levels with hearing aids. Our study addresses this issue by investigating phonological decoding processes among deaf children as a function of their speech abilities, in perception and in production, and their hearing loss with and without hearing aids.

Our paradigm was inspired by a project undertaken by Blanton, Nunnally, and Odom (1967). They used a similarity judgment paradigm with deaf teenagers (mean age = 16). Sixty short, high-frequency words in a binary choice format were presented to deaf and hearing participants. In one condition (30 items), the model word (FOUR) was an orthographic neighbor of one test item (FOUL) and a homophone with the other test item (FORE). Participants were told that they had to circle the word of the pair that they considered "best went with the stimulus word." The deaf participants chose homophones significantly less often (59.6% of the cases) than did hearing participants (83.7%). However, the authors did not calculate the scores of deaf participants according to chance levels. A recalculation of their data revealed that, despite the high standard deviation (7) mentioned by the authors, the responses of the deaf participants were significantly greater than the chance level, $t(144) = 4.92$, $p < .01$. Consequently, our hypothesis was that this paradigm could provide evidence for the use of phonological strategies among deaf people, despite their performing more poorly than controls.

We presented French hearing and deaf children with a similarity judgment paradigm that included variations in phonological and visuo-orthographic similarity between model and test items. Contrary to Blanton et al. (1967), the items we used (models and tests) consisted of pseudowords because our purpose was to investigate nonlexical phonological coding only. To control individual differences among deaf participants, deaf children were separated into two groups as a function of their speech skills, measured by both their speech production and their speech recognition skills.

In one condition, one of the two test items was a homophone of the model item. For example, for the model ***kise*** /kiz/, the test homophone was *kyse* /kiz/ and the concurrent test item was *kyne* /kin/. In comparison to Blanton et al.'s (1967) material, the visuo-orthographic similarity with model items was systematically controlled for the two test items.

The second condition implied similarity of the first syllables in disyllabic items. The syllabic structure of the French language is well documented. In French, the syllable is a particularly relevant linguistic unit in oral and written language. For French-speaking adults, the syllable is a unit of word recognition, as revealed by syllabic priming effects in oral word recognition (Mehler, Dommergues, Frauenfelder, & Segui, 1981), as well as a unit in speech production (Ferrand, Segui, & Grainger, 1996). For French-speaking children, evidence in support of the syllable as a reading unit may be found in Colé, Magnan, and Grainger's (1999) observations of first grade pupils in a letter detection task.

In the nasalization condition, the syllabic boundary of the first syllable was defined by the pronunciation of the letter *n*, depending on the context (***lanjier*** /lɑ̃.ʒie/, *landu* /lɑ̃.dy/, *lanud* /lɑ.nyd/). In the open–closed syllable condition, the syllabic boundary was defined by the phonological structure of the first syllable (CV or CVC), as determined by the presence of a vowel or a consonant following the second consonant of the item (***paulon*** /po.lõ/, *paulat* /po.lɑ/, *paulta* /pol.tɑ/).

We expected hearing children to make choices, according to phonological similarity, between items at a level superior to the chance level in all experimental conditions. We also expected such results among deaf children, but their results would depend on the quality of their speech abilities: the selection of phonologically similar items was expected to be more frequent for deaf children with higher speech abilities than for other deaf children.

METHOD

Participants

Deaf children. A total of 26 deaf children (11 males, 15 females) between the ages of 8;11 and 13;6 years (mean age = 11;1) participated in this experiment. All had a hearing loss greater than 70 dB in their better ear without aid (measured in tonal audiometry at frequencies of .25, .5, 1, and 2 kHz). Their deafness had been diagnosed before the age of 2 years, and all wore hearing aids. They were recruited in three specialized primary schools in northeastern France (seven classes in total). Their most common form of communication was French Sign Language. At school, sign language was alternated with oral methods in various ways, depending on the classes. Cued Speech was used at school in some courses and during speech and language therapy, but no child used it intensively as a common form of communication. Most parents of the participants had normal hearing, two children had deaf parents, and one child had a deaf father. The children had a normal level of intelligence, as tested by school psychologists using nonverbal tests (PM47 or WISC-R performance tests). They had no diagnosed behavior disorders, motor handicap, sensory deficit, or language difficulty other than those specifically associated with deafness.

Two tests were administered to the deaf children in order to separate them into poor and good speech groups. A speech perception test was adapted from Boon’s clinical test (1995), which was composed of 39 items. We decided to shorten this test to less than the standard duration of one hour. Several months prior to our experiment, the total version had been administered to 21 deaf subjects. We retained the 16 items that were the most correlated to the total score. Eventually, 8 words and 8 pseudowords were presented in Cued Speech (manual + oral) by the experimenter, who was assisted by a teacher. All the items were repeated three times. Children were asked to choose the written form among several alternatives with either similar coding or similar lip-read images. Six alternatives were presented for pseudowords, while four alternatives were presented for words. In order to succeed, children had to know the cued word associated with the lip-read images. The severity of their deafness would not enable them to succeed in the test solely on an acoustic basis. Finally, a score on a scale of 16 points was applied to each participant. The chance level corresponded to 3.2 points (20% of mean probability).

Speech production was recorded, and speech intelligibility was estimated by two independent speech-and-language therapists on a 5-point scale ranging from (1) "unintelligible" to (5) "clearly intelligible." Children had to name 7 colors, 21 numbers, and 22 pictures of ordinary objects. The scores of the two speech-and-language therapists were strongly correlated ($r = 0.96$, $r^2 = 0.91$, $p < .01$). Thus, the final score for each participant was the mean of the two scores.

The mean score for all deaf children in the speech perception test was 9.9/16 ($SD = 3.9$). The mean score for speech production was 2.3/5 ($SD = 1.5$). In the latter test, the distribution of the scores did not follow a normal curve, and the variability was particularly high. Two-thirds of the participants in the sample had scores below 2.5 points. In order to separate participants into two groups as a function of their general speech skills, criteria were chosen a posteriori, corresponding to mean scores in speech perception and a score in speech production, that permitted the division of the population. Ten participants had speech perception scores less than 10/16 and speech production scores less than 1.7/5. They constituted the poor speech group (D–). Ten participants were allocated to the good speech group (D+), defined by speech perception scores greater than 10/16 and speech production scores greater than 1.8/5. Six participants (23%) were not included in either groups because they did not meet the specified criteria: three presented perception scores inferior to 10 but production scores superior or equal to 1.8, and three presented the inverse profile. Individual scores of the deaf participants are presented in Table 1.

Control group. A total of 26 hearing children composed the control group (14 males, 12 females). They were between the ages of 6;9 and 10;2 years (mean age = 8;2). They were younger than the deaf participants, $t(50) = -8.46$, $p < .001$. They were recruited in a primary school in northeastern France. Fifteen children were in second grade, and twelve were in third grade. They were all native French-speaking and monolingual; none had repeated a school year, and none had any psychological, motor, sensory, or cognitive difficulties, as reported by their teachers.

The control group and deaf participants were matched on a written word recognition level and not on sentence or text reading level, on the grounds that more general reading processes (comprehension of sentences or texts) involve syntactic abilities that are not investigated in this study. As standard reading aloud tests could not be used with deaf children, the word reading level was evaluated by a lexical decision task presented in a limited time (1 minute) and by a test of orthographic recognition of frequent words (Khomsi, 1994).

The lexical decision task was created by the present authors: 20 frequent words and 20 pronounceable pseudowords that were not orthographic neighbors of real words were presented in random order. The frequency of the words had been controlled in a previous experiment (Transler, Leybaert, & Gombert, 1999). Children were asked to detect words and to reject pseudowords. They had to process as many items as they could in a minute. The mean number of correct responses was 25.8/40 ($SD = 10.4$) for the hearing participants and 25.7/40 for the deaf participants ($SD = 11.3$). The difference between the two groups was not significant, $t(50) < 1$.

Table 1. *Sex ratio, age, hearing loss with and without aids, scores to the CS test (speech perception) and to the speech intelligibility test (speech production) for deaf children, plus written word recognition scores for deaf and hearing children (lexical decision and word identification tests)*

	Sex	Age (months)	Deafness without aids	Deafness with aids	Cued speech (/16)	Speech intelligibility (/5)	Lexical decision (words per minute)	Word identification (/50)
Deaf participants D–								
D1	f	159	117	111	2	1.1	10	48
D2	m	130	110	65	4	1	32	39
D3	m	127	115	87	5	1.15	21	40
D4	m	108	108	57	5	1.25	26	39
D5	m	125	109	61	5	1.35	40	42
D6	m	126	109	65	5	1.7	29	46
D7	f	119	97	50	7	1.6	20	38
D8	m	135	102	47	9	1	33	46
D9	m	124	105	62	10	0.75	40	32
D10	m	145	100	52	10	1.1	40	39
M		129.8	108.5*	61.5*	6.2	1.2	29.1	40.9
SD		14.1			2.7	0.3	10.0	4.7
Deaf participants D+								
D11	f	158	120	120	10	4.5	24	49
D12	m	146	109	61	11	1.75	40	41
D13	f	161	106	64	12	2	40	47
D14	f	160	114	59	13	1.75	40	43
D15	m	119	100	42	13	3	34	35
D16	f	109	110	36	13	4.85	28	28
D17	f	101	72	45	14	4.4	25	39
D18	f	162	120	41	15	1.75	40	48
D19	f	107	99	35	15	4.4	40	47
D20	f	108	86	33	16	5	10	35
M		133.1	107.5*	43.5*	13.2	3.34	32.1	41.2
SD		26.3			1.9	1.4	10.2	6.9
Hearing participants (n = 26)								
M		97.8	—	—	—	—	25.8	42.4
SD		9.02	—	—	—	—	10.38	3.94

Note: M = mean; *SD* = standard deviation; * = median.

The second test, Epreuve collective d'identification des mots écrits (ECIM-E), was a collective test of word identification created by Khomsi (1994). Forty-five written items were each associated with a picture. Participants were required to circle the words that were correctly associated with the pictures and to cross out words that were not associated or that contained misspellings. The mean number of correct responses (words + pseudowords) was 42.4/50

(*SD* = 3.9) for the hearing children and 40.6/50 (*SD* = 7.1) for the deaf children. This difference was not significant, *t*(50) = 1.16, *ns*.

The mean of the scores of the two groups of deaf participants did not differ on age, written word recognition level, or hearing loss measured without hearing aids, *t*(18) < 1 in all cases. Their hearing loss, as measured with hearing aids, was not significantly superior when the means were considered (66 dB for D– and 53.6 dB for D+, *t*(18) = 1.18, *ns*), despite the median being greater for the D– group (62 dB) than for the D+ group (44 dB). It is worth mentioning that the fact that the written word recognition level was not different for deaf children with good speech and deaf children with poor speech was independent of the procedure we used to select the participants.

Material

The items were triplets of pseudowords: the model, a phonologically similar test item, and a second test item (concurrent item). Forty-four triplets were presented (see Appendix 1). Each triplet was presented on one page of a booklet. The model item was vertically centered on the left side of the page. Test items were presented on the right side, one above the other. The items of all conditions were mixed and presented in random order in the booklets.

Homophone condition. Two conditions of visuo-orthographic proximity were presented. The number of letters in common between the homophone and the model defined visuo-orthographic proximity. In the O+ condition, the visual proximity between both test items and the model was the same in that they differed by only one letter: for example, ***kyse*** /kiz/, *kise* /kiz/, *kyne* /kin/ (10 triplets). In the O– condition, the number of letters in common between models and nonhomophones was greater than the number of letters in common between models and homophones. In this condition, visual proximity favored nonhomophones: for example, ***nèbe*** /nɛb/, *naib* /nɛb/, *nère* /nɛr/ (10 triplets).

All pseudowords in both conditions were monosyllabic. Almost all items shared the same first letter in order to avoid an effect whereby the first letter would be more salient than the other letters. The grapho-phonological rules implied for decoding most of the pseudowords were simple and context-independent (except for three pseudowords, or 5%, for which pronunciation depended on the context: double consonants before *e* and the letter *s*, pronounced /z/, between two vowels).

Open–closed syllable condition. The first letters of the test items and the first letters of the model were identical (e.g., *bar*): that is, they all began with an onset, a vowel, and a consonant. The syllabic boundaries varied as a function of the presence of a cluster of consonants after the first vowel. In the CVC condition (***barser***, *bardi*, *barid*), the consonant following the first vowel was integrated in the first syllable (***bar.ser*** /bar.se/; 6 triplets). In the CV condition (***baru***, *barand*, *bardan*), the consonant following the vowel was integrated in the second syllable (***ba.ru*** /ba.ry/; 6 triplets). To avoid an eventual effect due to the length and the type of the first syllable, test items were created in pairs.

Model and test items of the CVC and CV conditions began with the same letters up to the probe consonant (e.g., ***bar.ser*** in the CVC condition and ***ba.ru*** in the CV condition). Model items of the CVC and CV conditions that began with the same letters were not presented in the same booklets in order to create a time delay between their processing by the participants.

Nasalization condition. The triplets were composed using the same principles as in the open–closed syllable condition. They began with the same letters, and the phonology of the first syllable varied as a function of the letter positioned after the letter *n*. In the CVN/ condition, the letter following the *n* in the model item was a consonant (***lanjier***, *landu*, *lanud*), and the *n* was integrated in the nasal vowel of the first syllable (***lan.jier*** /lɑ̃.ʒje/; 6 triplets). In the CV/N condition (***lanut***, *lanic*, *lanci*), the letter following the *n* in the model item was a vowel (***lanut***); the *n* had a consonant status, the syllabic boundary occurred before it (i.e., after an oral vowel: ***la.nut*** /la.ny/), and the *n* was integrated in the second syllable (6 triplets). The matching of triplets was the same as in the open–closed syllable condition.

Control tasks: Word-likeness and syllabification

Two control experiments were conducted for the disyllabic items to investigate the similarity between experimental disyllabic pseudowords and real words and to verify whether the syllabic structure was clear. The participants were 8 children from the second grade and 11 children from the third grade (mean age = 8;2). As a basis of their selection, they were diagnosed as not being subject to any auditory, language, or learning deficits. They were all native French speakers, and no one was bilingual. They had not participated in the experiment of similarity judgment (those participants had been recruited from another school in the same area).

For the control of word-likeness, test items were presented by pairs (e.g., *landu* vs. *lanud*), and pairs were presented randomly. Children were told that two little boys had invented new words; one boy was French and the other lived far away in a foreign country. They were told that the French boy's new words looked like real French words, whereas the words invented by the other boy did not look like French words. Participants were asked to guess for each written word pair which word had been invented by the French boy and to circle it. In the nasalization condition, words beginning with a nasal syllable (CVN/) were chosen by 53.9% of the total number of participants. This score was not significantly different from the chance level, $t(18) = 1.43$, *ns*. In the open–closed syllable condition, words beginning with a CV syllable were chosen by 60.5% of the participants. This score was significantly superior to the chance level, $t(18) = 3$, $p < .01$; thus, pseudowords with a CV syllable were judged as more similar to real words than were words with a CVC syllable. This phenomenon is congruent with the fact that in French words with a CV syllable are more numerous than words with a CVC syllable.

For the control of syllabic boundaries, an explicit syllabic segmentation was presented to the same participants following the first test. Children were told what a syllable is, and examples were given to show them how to segment words into two syllables. They were then given a list of pseudowords and asked to write a slash between each set of two syllables. The rates of unexpected responses were low: CVC, 9%; CV, 5%; CVN/, 2%; and CV/N, 7%. Consequently, all items were considered as valid.

Procedure

All children were seen in their classrooms with their teachers present. They were presented with the lexical decision test and then the word identification test (20 minutes). These two tests were followed by the speech perception tests for deaf participants. The total duration of this first test session was approximately one hour for the deaf children. In addition, an individual session for deaf children was organized in the following days for the speech intelligibility test; children were told that their voices were being recorded, and that they should speak as well as they could.

The similarity judgment task was presented during a second session in the presence of a teacher or speech therapist, who was told that he or she could intervene to reformulate instructions but not to give new information. A first booklet was distributed to all children. The pages were randomized so that no two children had the same booklet. In each booklet, no two model items had the same beginning: for instance, the pseudowords ***paulon***, *paulat*, *paulta* and ***paulni***, *paulto*, *paulot* did not appear in the same booklet. The second booklet was given to the children immediately after the first. The order of presentation in the booklets was balanced. The children were told that all the words were "invented" (i.e., did not exist in reality). They were told that they had to choose words on the right side of the page that seemed most like the items on the left side. Instructions were given in sign language to the deaf children. In sign language, the expression used could be translated as "choose the word that is about the same as." Three examples were given. In those examples, no phonological strategy was primed because both orthographic and phonological similarity would enable the children to find the item that was most similar to the model (e.g., ***trouf***, *traf*, *brok*). The experimental task was not time limited. It took about 20 minutes.

RESULTS

In each condition, the dependent variable was the number of choices of test items that were phonologically most similar to the model item. The results in the homophony, open–closed syllable, and nasalization conditions were analyzed separately. In each condition, data were analyzed with a general ANOVA followed by planned comparisons (hearing vs. D+; D+ vs. D–). Then the scores in each group were compared to the chance level (50%).

Homophone condition

Data were analyzed by a general ANOVA with a 3 × 2 design (Group [hearing, D+, D–] × Orthographic Similarity [O+, O–]), with the last factor as a repeated measure and participants as a random factor. The percentages of choices of the

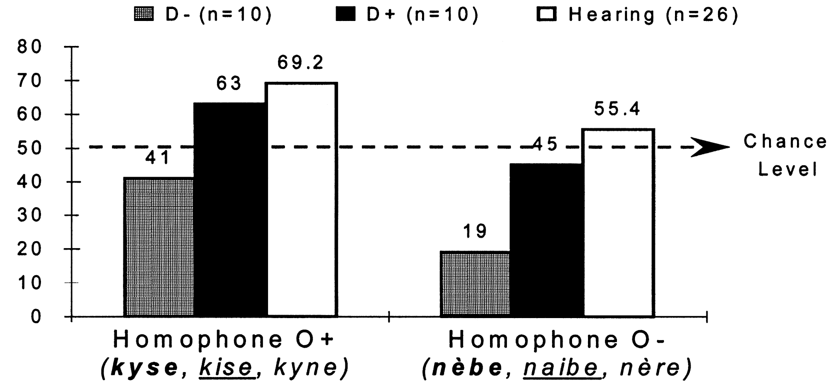

Figure 1. Percentages of phonological similarity choices in the homophone conditions (O+ and O–) for deaf (D+ and D–) and hearing children.

phonologically similar items for the three groups of participants are presented in Figure 1. The effect of orthographic similarity was significant, $F(1, 43) = 30.16$, $p < .001$, without significant interaction among the groups, $F < 1$. The effect of group was significant, $F(2, 43) = 11.4$, $p < .001$.

The first planned comparisons showed that the scores of the hearing children did not differ significantly from those of the D+ group, $F(1, 43) = 1.5$, *ns*. In both groups, scores were superior to the chance level in the O+ condition: hearing, $t(25) = 5.29$, $p < .01$; D+, $t(9) = 2.05$, $p < .05$. However, the scores of both groups were not superior to the chance level in cases where orthographic proximity was in competition with phonological proximity: hearing, $t(25) = 1.01$, *ns*; D+, $t(9) = -1$, *ns*. As expected, hearing children were sensitive to phonological proximity between items, though this effect disappeared when orthographic similarity was in competition with phonological similarity. Deaf children with high speech level scores showed the same pattern of results. This is interpreted as evidence supporting the existence of phonological decoding for deaf children with high speech abilities.

The second planned comparison showed that the scores of deaf children with the poor speech abilities were significantly lower than those of the D+ group, $F(1, 43) = 8.6$, $p < .01$. In the condition O+, the choices of the D– did not differ from the chance level, $t(9) = -1.71$, *ns*, preventing us from attempting any interpretation regarding their reading strategy. However, in the O– condition, deaf children chose homophones at a lower level than the chance level, $t(9) = -6.43$, $p < .01$; the visuo-orthographic proximity between models and tests determined their responses.

Open–closed syllable condition

Data were analyzed by an ANOVA with a 3 × 2 design (Group [hearing, D+, D–] × First Syllable [CVC; CV]), with the last factor as a repeated measure and participants as a random factor. The percentages of choices of the phonologi-

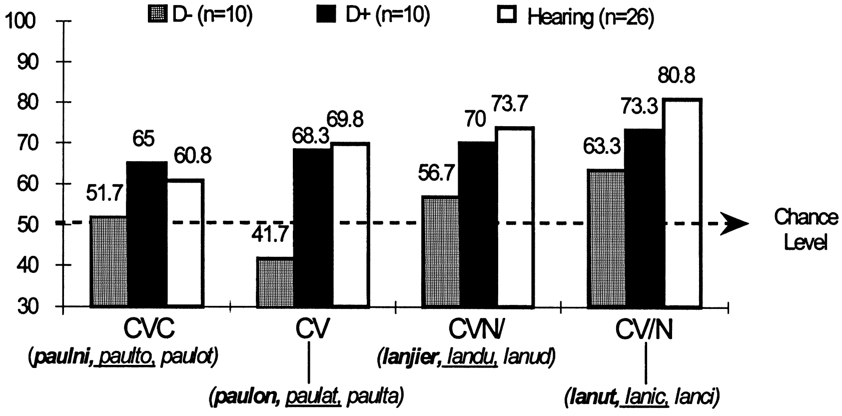

Figure 2. Percentages of phonological similarity choices in the open–closed syllable condition (CVC, and CV) and in the nasalization condition (CVN/ and CV/N) for deaf (D+ and D–) and hearing children.

cally similar items for the three groups of participants are presented in Figure 2. The main effect of group was significant, $F(2, 43) = 4.43$, $p < .05$. The effect of first syllable was not significant, $F(1, 43) < 1$, nor was the interaction, $F(2, 43 = 1.21$, *ns*. The first planned comparison showed that there was no significant difference between hearing children and deaf children with good speech skills, $F < 1$. The choices of hearing children were significantly higher than the chance level: CV, $t(25) = 3.44$, $p < .01$; CVC, $t(25) = 2.64$, $p < .01$. However, the scores of deaf children with good speech skills, compared with the chance level, differed as a function of the phonological status of the first syllable. In the CV condition, their choices were significantly higher than the chance level, $t(9) = 3.16$, $p < .05$, whereas this was not the case in the CVC condition, $t(9) = 1.78$, *ns*. The lack of significant difference between scores in CVC and the chance level for the D+ group was unexpected because the scores of deaf children in the CVC condition were numerically higher than those of hearing children (65.0% vs. 60.8%). The lack of significance is the consequence of the low number of deaf participants integrated in this group, as well as a standard deviation higher in the deaf group than in the hearing group (respectively, 26.5% and 21.0%). These factors diminish the authority of the statistical test results.

The second planned comparison showed that the results of D– participants were significantly inferior to those of the D+ group, $F(1, 43) = 6.2$, $p < .05$. Their results were clearly not different from the chance level for each condition of the first syllable phonological structure: CVC, $t(9) < 1$, *ns*; CV, $t(9) < 1$, *ns*.

To summarize, in this condition the scores of deaf children provide support in favor of the existence of sensitivity to the phonological structure of syllables only for deaf children with good speech and in the CV condition.

Nasalization condition

Data were analyzed by an ANOVA with 3 × 2 design (Group [hearing, D+, D–] × First Syllable [CVN/; CV/N]), with the last factor as a repeated measure and participants as a random factor. The percentages of choices of the phonologically similar items for the three groups of participants are presented in Figure 2. The effect of group was significant, $F(2, 43) = 4.14$, $p < .05$. There was no significant effect of the first syllable, $F(1, 43) = 1.33$, *ns*, nor any interaction, $F(2, 43) < 1$.

The first planned comparison showed that there was no significant difference between the scores of hearing and D+ participants, $F < 1$. Hearing and D+ participants made choices superior to the chance level in both conditions: in the CVN/ condition, hearing, $t(25) = 5.33$, $p < .01$, deaf D+, $t(9) = 2.25$, $p < .05$; in the CV/N condition, hearing, $t(25) = 7.91$, $p < .01$, deaf D+, $t(9) = 2.94$, $p < .01$. This pattern of results showed that hearing and deaf participants with good speech were sensitive to similarity at a syllabic level.

The second planned comparison showed that the difference between the scores of the D– and D+ groups was not significant, $F(2, 43) = 2.6$, $p > .05$. The scores of the D– deaf group were not significantly different from the chance level in the CVN/ condition, $t(9) = 1.08$, *ns*, but were slightly higher than the chance level in the CV/N condition, $t(9) = 2.23$, $p < .05$. We will return to the question of whether the visuo-orthographic properties of items could account for those results independently from their phonological properties.

Comparison between open–closed syllable and nasalization conditions

A posteriori, it was decided to compare the scores in the open–closed syllable conditions and the scores in the nasalization condition because the latter seemed numerically higher for all groups. Data were analyzed by an ANOVA with a 3 × 2 design (Group [hearing, D+, D–] × Type of Disyllable [open–closed syllable, nasalization]), with the last factor as a repeated measure and participants as a random factor. There was indeed a main effect of the disyllabic item type, with unexpectedly higher scores in the nasalization condition than in the open–closed syllable condition, $F(1, 43) = 9.9$, $p < .01$. Those results will be discussed with regard to the visuo-orthographic properties of items in each condition. Finally, we found the same group effect that we observed earlier, $F(2, 43) = 6.15$, $p < .001$, but the interaction was not significant, $F < 1$.

DISCUSSION

In this experiment, we examined the evidence for phonological decoding process among deaf children in a task of similarity judgment between pseudowords. Our main interest was to determine whether deaf children would be sensitive to phonological similarity between monosyllabic homophones and between disyllables sharing the same first syllable, as defined by open structure or by nasalization. Individual differences were controlled: deaf children were separated into two groups as a function of their speech production and perception abilities. Their scores were compared with a control group of hearing children matched on word reading level.

Monosyllabic homophones

In this condition, the scores of hearing children were superior to the chance level when the visuo-orthographic similarity between test items and control items was controlled. However, when visuo-orthographic similarity was in competition with phonological similarity, no dominant strategy was observed.

As expected, the results of deaf children differed significantly as a function of their speech skills. Regarding the deaf children with the highest speech scores (D+), the selection of similar items was superior to the chance level in the same conditions as for the hearing group. As expected, they chose the homophone test item in cases where the visuo-orthographic similarity between both test items and the model item was equal (homophone condition O+). This result is congruent with Blanton et al.'s (1967) observations concerning real words: deaf people would choose homophonic words when visuo-orthographic similarity between model items and nonhomophone items was controlled (e.g., ***four***, *fore*, *foul*). Our results also extend Blanton et al.'s findings because our items were only pseudowords, making direct access to the phonological form of the items impossible. We may conclude from our data that the deaf children used phonological decoding processes at a sublexical level to read the items and then to solve the experimental task. They could possibly have applied grapho-phonological conversion to diverse reading units (graphemes, rimes, or others). It is also possible that they used sublexical analogy processes in their reading (Gombert, Bryant, & Warrick, 1997; Goswami, 1988, 1998), leading to a phonological assembly in a large sense (Peereman, 1991). These observations alone cannot fully account for one interpretation over another.

On the contrary, deaf children with poor speech skills did not show any clear evidence in favor of phonological decoding in the homophone condition; their scores were not significantly superior to the chance level. This result is congruent with several studies indicating that deaf youngsters with poor speech did not show evidence of phonological processing in reading tasks (e.g., Beech & Harris, 1997; Hanson, 1986; Leybaert & Alegria, 1993, 1995). This result does not mean that such children have not developed any phonological representations. Strictly speaking, we cannot conclude whether children are deprived of phonological representations or whether they have some but do not use them spontaneously in reading. This second hypothesis is plausible because some studies have demonstrated that deaf participants who were sensitive to the phonological properties of material in other experimental paradigms like working memory and spelling did not show any evidence of phonological coding during reading (Burden & Campbell, 1994; Waters & Doehring, 1990). In the absence of any evidence of a phonological decoding strategy in this task, we would surmise that these deaf children adopted another strategy in order to respond to the demands of the task. In the condition where nonhomophones shared more letters in common with the models than did homophones (O– condition), deaf children with poor speech clearly adopted a visuo-orthographic strategy.

Sensitivity to syllabic structure and syllabic boundaries

When disyllables were presented, the scores in the control group of hearing children were significantly superior to the chance level. Children were sensitive to the fact that two pseudowords shared the same first syllable, as defined by the open or closed structure or by the nasal or oral status of the vowel in the first syllable. This revealed that hearing children were sensitive to the syllables of the written items. Thus, those results are in accordance with studies that have underlined the role of the syllable in reading in French (for children, see Colé et al., 1999; Magnan & Colé, 1999).

Another question was whether deaf children with good speech would be sensitive to syllabic structure. In the open syllable condition (CV) and the nasalization condition, deaf children with good speech chose items sharing syllables with similar boundaries at a significantly higher level than chance, just as hearing children did. The evidence was less strong for CVC (closed) syllables. A possible explanation is that children find it more difficult to read items containing closed syllables or consonant clusters than items containing only open syllables (Sprenger-Charolles & Siegel, 1997). As mentioned before, CVC syllables (closed syllables) are rarer than CV syllables (open syllables) in French, and perhaps this is why CVC items obtained significantly lower scores in the word-likeness task. Thus, a complementary hypothesis is that deaf children would choose CV test items more often than CVC items because of their greater degree of word-likeness. However, this explanation is very unlikely because, if that were the case, this effect should also have been observed in the D– group. Thus, the effects observed on CV items were more likely due to the participants' sensitivity to the phonological similarities between items. From the results observed on the rest of the material, we can conclude that deaf children with good speech level were sensitive to the syllabic structure of the items and that they were able to perform a syllabic parsing.

To our knowledge, this is the first time that sensitivity to syllabic structure of written material has been evidenced and related to speech abilities among deaf children. Indeed, Transler et al. (1999) observed a utilization of syllabic units during a copying task, but they found no strong evidence for phonological coding in this task, nor any link with speech abilities and the use of syllabic reading units. It is worth mentioning that the forced choice demanded by our paradigm, combined with the linguistic constraints of our material (pseudowords instead of words), probably amplified the pertinence of the phonological strategies necessary to find an adequate response. Future studies should aim to detect whether sensitivity to syllabic structure occurs in more natural reading conditions among deaf children with good speech levels.

For deaf children with poor speech, given the absence of significant results in the O+ homophone condition, one would not have expected any significant result in conditions implying disyllabic items. Indeed, phonological decoding was expected to be more difficult to do on disyllabic items than on monosyllabic items. The primary reason is that the items were longer (disyllabic vs. monosyllabic) in the homophone condition. Moreover, in the nasalization condition, the grapho-phonemic conversion of the letter *n* depended on the context, and in the open–closed syllable condition, the consonant cluster created a pronounceability difficulty. Those predictions were only partially verified.

In the open–closed syllable condition, scores of deaf children with poor speech were not different from the chance level. However, their scores were clearly superior to the chance level in the nasalization condition (CV/N). An explanation in terms of word-likeness can be discarded because the results obtained in the control test of word-likeness of model items in the nasalization condition were not significantly different as a function of the structure of model items. Moreover, in post-hoc tests, no significant difference was observed in this deaf sample between scores in the CVN/ and CV/N conditions. Finally, in the CV/N condition, their scores were numerically superior to their scores in all other conditions. The high scores of deaf children with poor speech in the nasalization conditions, especially in comparison to their lower scores in the open–closed syllable condition, were not expected.

A closer look at the characteristics of the consonant clusters implied in the nasalization and open–closed syllable conditions reveals that frequency phenomena differed within the two conditions. For items containing consonant digrams, the frequency of consonant digrams containing a syllabification was significantly higher in the nasalization condition than in the open–closed syllable condition. In fact, digrams containing a syllabification between *n* and the consonant ($n +$ consonants in CVN/ and CV/N triplets, either in models or in test items) are more frequent than digrams containing a syllabification between the two consonants in triplets of the CVC and CV conditions.[1] It is possible that deaf children with poor speech were sensitive to those frequency phenomena that imply digram frequency and the orthographic syllabification phenomena.

This interpretation would be in line with the data obtained by Hanson. This author systematically observed that deaf adults were sensitive to orthographic structure during spelling (Hanson, Shankweiler, & Fisher, 1983), during a letter report (Hanson, 1982), and during letter detection and word-like judgment (Hanson, 1986). She observed that even deaf adults with poor speech were sensitive to orthographic structure, and that their use of positional frequency information was the same as in hearing people (Hanson, 1986). Our data suggest that deaf children, whatever the quality of their oral language, have developed orthographic sensitivity to frequency phenomena determining syllabic boundaries. Future studies should investigate to what extent the sensitivity of deaf children to frequency phenomena is independent of phonological abilities.

Speech abilities, hearing loss, and phonological decoding

Regarding our results, an important question concerns the relationships existing between the abilities we measured among deaf children in the D+ group and their experimental results. We chose our group of deaf children so that they would share several characteristics. They had better intelligibility and better speech perception (auditorily and visually measured); they also showed better hearing thresholds, as measured with their hearing aids. This set of particularities is not surprising because other studies have evidenced close links between some of these variables. Audiological studies showed that hearing level, as measured with conventional aids or cochlear implants, were positively correlated with auditory speech perception and intelligibility (Osberger, Maso, & Sam, 1993). Dodd, McIntosh, and Woodhouse (1998) observed significant positive relationships between lip-reading abilities, speech intelligibility, and visual speech perception among young children with hearing impairments. However, the nature of the links between hearing, visual speech perception, and speech production abilities is far from clear. Thus, it would be premature to give an interpretation of the relationships observed between one of those variables that characterized the D+ group and the experimental results of this group. For instance, the hearing level in itself is not sufficient to predict speech perception and intelligibility because there are still important disparities when the hearing level is equivalent, especially among profound deaf children (Osberger et al., 1993). It is also not possible to determine whether speech perception (auditory and visual) precedes and determines speech intelligibility or whether those variables develop in interaction (Dodd et al., 1998).

In spite of the fact that the link between those variables has yet to be elucidated, it is clear that most of those variables, taken alone or together, have already been found to predict important individual differences among the deaf population concerning the phonological coding of written material (Beech & Harris, 1997; Conrad, 1979; Hanson, 1986; Leybaert & Alegria, 1993, 1995; Reynolds, 1986). Our study reinforces the evidence in this area, showing that there is a strong relationship between deaf children's speech abilities, taken as a whole, and their phonological coding abilities.

Reading strategies among deaf children

Reading strategies among deaf children are at once more diverse and more difficult to observe than reading strategies in the hearing population because of their specificity. First, phonological decoding is probably one of the most investigated reading strategies among deaf children because of its essential impact on the whole process of reading development. In fact, we designed this study with the purpose of observing this type of reading strategy. The utilization of phonological processes during reading in deaf people is heterogeneous and difficult to observe; phonological representations not only are underspecified, but also have multiple sources. However, we managed to find evidence for phonological assembly during silent reading in deaf children who had the most effective speech. Our results are in accordance with the results of Beech and Harris (1997). Another question to raise in future studies is whether the phonological decoding could be automatically evoked by deaf children during silent reading, a question that still lacks an affirmative answer (Burden & Campbell, 1994; Waters & Doehring, 1990).

Second, orthographic reading strategies have to be scrupulously studied in this population. In particular, orthographic strategies could be considered as developing independently from the development of abilities to use grapho-phonological assembly, as suggested by the double-foundation model of orthographic development proposed by Seymour (1997). Children could develop some orthographic representations (i.e., a sensitivity to a frequent string of letters in written language) in spite of their difficulties to master phonological decoding processes. However, this is only a hypothesis and requires more in-depth studies. At present, studies dealing with this specific topic are rare (Pacton, Perruchet, Fayol, & Cleeremans, in press). The authors who did observe deaf people's sensitivity to orthographic phenomena rarely dissociated legality from pronounceability (Hanson, 1986) Nevertheless, our results and results observed by Hanson (1986) supply some evidence in favor of this hypothesis.

Finally, other reading strategies that we have not controlled in this experiment could also have been activated. There are indeed specific reading strategies among deaf people consisting in converting written material into sign or gesture representations, such as sign language and fingerspelling (Hirsh-Pasek, 1987; Treiman & Hirsh-Pasek, 1983). It is possible that these representations relate, more or less directly, to orthographic or phonological representations, but this, again, is a question for ongoing debate.

APPENDIX 1

Experimental triplets for the homophone, open–closed, and nasalization conditions: model items (Mod.), phonologically similar test items (Phono.), concurrent test items (Conc.), and mean bigram frequency of test items

Homophone condition

	Homophones O+				Homophones O–		
	Mod.	Phono.	Conc.		Mod.	Phono.	Conc.
	kyse	kise	kyne		lemme	laime	lumme
	denc	danc	dene		vaite	vette	vatte
	drun	drin	dron		nèbe	naibe	nère
	jeau	jaux	teau		neile	nèle	neple
	toal	toil	toul		jain	jin	jern
	clun	klun	clus		kade	quade	kafe
	drage	draje	droge		luphe	lufe	lupre
	vense	vence	venre		vasse	vace	vause
	rac	rak	ruc		tac	taque	toc
	fouse	fouze	fonse		raxe	rakse	rane
Big. fq.	*M*	820	1,128	Big. fq.	*M*	955	1,134
	SD	481	799		*SD*	472	714
	Comparison: $t(9) = -1.18$, *ns*				Comparison: $t(9) < 1$		

Nasalization condition and open–closed syllable condition

	Nasalization				Open–closed syllable		
	Mod.	Phono.	Conc.		Mod.	Phono.	Conc.
CV/N	lanut	lanci	lanic	CV	fabin	fabas	fabsa
	sonoc	sonfi	sonif		paulon	paulat	paulta
	nenon	nendu	nenud		saran	sarot	sarto
	tinou	tindan	tinand		baru	barand	bardan
	bonaux	bonfa	bonaf		bulir	bulap	bulpa
	fanier	fanca	fanac		mirin	mirus	mirsu
CVN/	lanjier	landu	lanud	CVC	fabtin	fabsou	fabous
	songa	sonto	sonot		paulni	paulto	paulot
	nendou	nenfie	nenief		sarpaux	sartou	sarout
	tinfaux	tinsa	tinas		barser	bardi	barid
	bonquis	bonta	bonat		bulpeau	bulson	bulons
	fanja	fanro	fanor		mirgon	micro	miroc
Big. fq.	*M*	769	788	Big. fq.	*M*	703	627
	SD	196	141		*SD*	343	232
	Comparison: $t(11) < 1$				Comparison: $t(11) < 1$		

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NOTE

1. The frequency of the digrams was evaluated with the French data base BRULEX (Content, Mousty, & Radeau, 1990). The calculation of frequency takes into account the orthographic syllabification between two letters (established on the basis of phonological syllabification, as defined by sonority principles). For instance, in French, the digram B/S has a frequency of 49 (per million) and the digram N/C has a frequency of 610. It means that the digram N/C, with a syllabic boundary after the letter *n*, is more frequent than the digram B/S, with a syllabic boundary after the *b*. The mean frequency of digrams from the nasalization condition is 494 for nonexpected test items in the CV/N condition, 234 for model items in the CVN/ condition, and 622 for expected test items in the CVN/ condition. Thus, digram frequency is higher than in the open–closed condition: 173 in the CV condition, $t(10) = 3.49$, $p < .01$, 86 in the CVC condition, $t(10) = 1.6$, *ns*, and 191 in the CVC condition, $t(10) = 2.16$, $p = .05$.

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