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Orthographic Learning in French-Speaking Deaf and Hard of Hearing Children

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ABSTRACT

Purpose: Children are assumed to acquire orthographic representations during autonomous reading by decoding new written words. The present study investigates how deaf and hard of hearing (DHH) children build new orthographic representations compared to typically hearing (TH) children.
Method: Twenty-nine DHH children, from 7.8 to 13.5 years old, with moderate-to-profound hearing loss, matched for reading level and chronological age to TH controls, were exposed to 10 pseudowords (novel words) in written stories. Then, they performed a spelling task and an orthographic recognition task on these new words.
Results: In the spelling task, we found no difference in accuracy, but a difference in errors emerged between the two groups: Phonologically plausible errors were less common in DHH children than in TH children. In the recognition task, DHH children were better than TH children at recognizing target pseudowords. Phonological strategies seemed to be used less by DHH than by TH children who very often chose phonological distractors.
Conclusions: Both groups created sufficiently detailed orthographic representations to complete the tasks, which support the self-teaching hypothesis. DHH children used phonological information in both tasks but could use more orthographic cues than TH children to build up orthographic representations. Using the combination of a spelling task and a recognition task, as well as analyzing the nature of errors, in this study, provides a methodological implication for further understanding of underlying cognitive processes.

Mastering literacy—the ability to read, write, and process print—is a necessary skill in most societies, be it to read books or subtitles, write e-mails, or access higher education. Learning to read and spell words usually requires direct instruction and a long training in elementary school. In alphabetical scripts, children must understand the system of correspondences between speech units (phonemes) and written units (graphemes); this learning challenge increases when the correspondences are not transparent and systematic (Seymour et al., 2003). English and French have often been studied given their level of inconsistency in phoneme–grapheme correspondences, allowing researchers to understand potential difficulties arising at different stages of reading and spelling acquisition. In French, one phoneme can be spelled by more than three different graphemes on average, in monosyllabic words (Ziegler et al., 1996). For example, the phoneme /s/ can be spelled “s” or “c,” in *silence*, “sc” in *science*, and “ss” in *passage* (Peereman & Content, 1999; Peereman et al., 2007). Knowing the phoneme-to-grapheme conversion rules in French only makes it possible to correctly spell half of the common words (Véronis, 1988). By contrast, correspondences from print to speech are more systematic; the grapheme “ss” is always pronounced /s/ in French, as in the word *passion* (/pasjɔ̃/). This asymmetry in conversion rules leads to a longer spelling than reading acquisition period, which makes French a good candidate to study spelling development and orthographic learning, that is, the creation of orthographic representations for written words encountered for the first time.

Initial models of spelling acquisition adopted a stage-based approach, in which children’s ability to use

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conversion rules or contextual information to read or spell words was explained by mechanisms specific to a developmental stage (e.g., Ehri, 1995, 2000, 2005; Frith, 1985). At the final stage (consolidated alphabetic phase) of Ehri's model, children have stored so many orthographic representations of words in memory that they are assumed to be aware of spelling conventions of their own orthographic system (Ehri, 2000). Ehri's model has been criticized for neglecting statistical learning[1] of orthographic cues that children acquire and use to spell words (Cassar & Treiman, 1997; Pacton et al., 2002). Yet, early implicit knowledge of writing conventions (Treiman & Yin, 2011) and language-specific orthographic regularities (Kessler et al., 2013) was evidenced in children by the end of kindergarten based on their invented spellings. For example, Kessler and colleagues asked 4-year-old Portuguese speakers to spell 12 words. Based on the invented spellings of 31 "pre-phonological" spellers whose written productions were phonologically unacceptable or illegal, children who demonstrated statistical learning strategies (i.e., frequently spelling two-letter chunks encountered in children's books) performed better 2 years later in a spelling test than children who only spelled the letters of their own names. Thus, not only does phonological knowledge of phoneme–grapheme correspondence play a role in the acquisition of spelling, but so does sensitivity to orthographic models. Furthermore, item-based approaches rather than stage-based approaches seemed preferable to study orthographic learning. Indeed, the characteristics of individual written words are considered to explain spelling abilities. A given word could be easily spelled at an early stage, thanks to its high consistency in phoneme–grapheme conversions or to its high frequency of occurrences in texts, whereas other words were continually misspelled although phoneme–grapheme conversion rules are mastered (Sprenger-Charolles et al., 1998). This is especially true for an orthography with many inconsistencies like French, which does require orthographic knowledge to spell words correctly.

Currently, a well-accepted framework to study orthographic learning is based on the self-teaching hypothesis proposed by Share (1995, 1999). The model he put forward is based on existing reading models that primarily consider the characteristics of the written words encountered in the underlying reading mechanisms. For example, the dual-route model (Coltheart et al., 1993) distinguished a phonological decoding route to read unfamiliar words and a lexical route to read words that are already encoded in the readers' mental lexicon. These two mechanisms are used in parallel during reading, although the lexical pathway is considered more efficient for expert reading. Thus, robust orthographic representations stored in the mental lexicon enable fast and automatic word recognition. In the self-teaching hypothesis, Share (1995) proposed that the acquisition of accurate orthographic representations, necessary to become an expert reader, involves the process of phonological decoding of unfamiliar words in autonomous reading. Each attempt to decode an unfamiliar word is an opportunity to "self-teach" and encode its orthographic representation in the mental lexicon. Phonological decoding could be partial and laborious in beginning readers (Wang et al., 2011) but sufficient to encode enough orthographic information that will help to successfully recognize the unfamiliar word encountered again. Importantly, the quality of orthographic representations varies in accordance with the number of expositions: The more a child is exposed to a given written word and accurately decodes it, the more its orthographic representation in memory is consolidated. Hence, assessing the development of new orthographic representations is necessary to understand the type of information encoded during phonological decoding and their influence on visual word recognition and spelling production.

To test for the development of new orthographic representations, Share (1999) developed the self-teaching procedure, initially in Hebrew-speaking children in Grade 2. First, readers incidentally encounter and decode novel words (target pseudowords) while reading a short text reading (exposure phase), creating new orthographic representations not based on prior phonological or semantic knowledge. Here is an example from Cunningham et al. (2002, p. 197): "North of Greenland is a place they say is the coldest place in the world. The name of the city is Yait. In Yait there is snow and ice all year round. (. . .)" After this phase, orthographic learning is typically assessed through a written production task (spelling dictation task) and an orthographic choice task (recognition task), using distractors that include homophonic and visual foils (e.g., *yait*, *yate*, *yoit*, *yiat*). This assessment helps to understand how children memorize new orthographic representations, even partial ones. In Share, target spellings were chosen significantly (up to 3 times) more often than homophonic foils, indicating an orthographic learning. Given the high percentage of pseudowords accurately decoded (over 84%), Share argued that phonological decoding was a "sine qua none" condition in orthographic learning. Since then, many studies investigated orthographic learning with self-teaching paradigms and confirmed the relation between phonological decoding skills and orthographic learning (see Li & Wang, 2023, for a systematic review). These studies varied the consistency of the spelling system, the number of exposures to the

[1]Statistical learning in spelling acquisition often refers to the ability to extract probability-based orthographic patterns or knowledge in the environmental writing system. At early stages, this ability results mostly from print exposure in children's books or own names (Treiman, 2017).

targets, the delay between the exposure and assessment phases, the nature of the targets (real words, pseudohomophones), the type of reading (aloud or silent), the context in which the targets appeared (in text or isolation), and children's grade or population (e.g., Bosse et al., 2015; Bowey & Muller, 2005; Cunningham, 2006; de Jong et al., 2009; Nation et al., 2007; Share, 2004; Tamura et al., 2017; Wang et al., 2017; Wass et al., 2019). The implication of phonological decoding in orthographic learning was confirmed albeit nuanced. Specifically, Nation et al. (2007) found examples where readers did not successfully decode some items but were able to spell them correctly, and vice versa. This finding suggests that phonological decoding is important but not the only factor at work when learning the orthographic representations of new words: Other orthographic knowledge is used such as the sensitivity to orthographic regularities (Nation et al., 2007; Pacton et al., 2014).

Those results were found in typically hearing (TH) children, but the challenge of learning to read and spell is harder for deaf and hard of hearing (DHH) children because of their generally underspecified phonological representations compared to TH children (Dyer et al., 2003). Most studies showed that DHH children have, at the end of primary school, a reading and spelling delay compared to TH children of the same age (see Mayer & Trezek, 2018, for a review). Yet, spelling skills generally appear to be less impacted than reading skills in DHH children, whatever their method of communication (sign or spoken language), and their auditory rehabilitation, with or without hearing aids or cochlear implants (CIs; Herman et al., 2017). Indeed, spoken language knowledge (e.g., receptive vocabulary and speechreading) and phonological awareness are predictors of DHH children's reading abilities, but less so for spelling abilities (Kyle & Harris, 2006, 2011).

The use of phonological strategies in spelling abilities has been investigated in written word production tasks, showing that deaf children successfully use phoneme-to-grapheme knowledge to spell words (see Grantham, 2020, for details). Phonology seems to play an important role, be it through spoken language units like phonemes or visual language units like fingerspelling (Lederberg et al., 2019). Importantly, DHH children extract phonological spoken units not only from auditory information but also from audiovisual (speechreading) information, as demonstrated by several studies. For example, omissions of sounds articulated in the posterior portion of the vocal tract, for example, /k/ and /g/ sounds, were reported in spelling (e.g., Dodd, 1976; Leybaert & Alegria, 1995), supposedly because these phonemes are invisible in speechreading (Alegria, 1998; Harris & Moreno, 2004). Phonological strategies in DHH children's spelling were also highlighted by studies on communication tools (e.g., cued speech) or hearing devices (e.g., CI) that are known to improve access to audio–visual phonology. Cued speech, which consists of a visual system of manual gestures and hand position added to lipreading, provides full access to the spoken word phonology (Cornett, 1967). A positive impact of cued speech has been demonstrated on DHH children's spelling skills (Colin et al., 2007, 2013; Leybaert, 2000; Leybaert & Lechat, 2001; Rees & Bladel, 2013) since the gap in spelling accuracy between TH and DHH children vanished when the latter were intensively exposed to cued speech. Hence, early access to accurate visual phonological information enables phonologically correct spelling of familiar and less familiar words. Furthermore, hearing technology advances also improved access to audio–visual phonology, despite some limitations in transmitting fine structures of the acoustic speech signal (Lorenzi et al., 2006; Pisoni, 2008). The number of children fitted with hearing aids or CIs at an early age has increased in the last decades (Naik et al., 2021), and several studies investigated the technology effect on spelling (Bell et al., 2019; Harris & Terlektsi, 2011; Hayes et al., 2011; Roy et al., 2015; Simon et al., 2019). Overall, no difference was found in spelling accuracy between the DHH children with CI and TH children matched for chronological and reading age. However, spelling error analysis revealed differences in spelling strategies between the two groups. For example, Hayes et al. (2011) showed that phonologically plausible errors (PPE), for example, "braine" for *brain*, were less numerous in 8-year-old children with CI (44%) compared to TH controls (75%) in a written picture naming task. Conversely, the amount of phonologically unacceptable errors (PUE), for example, "briane" or "bran" for *brain*, in deaf children with CI was 3 times higher than in TH children. The same pattern of spelling error distribution was found in French by Simon et al. (2019) using the same design. The authors concluded that children with CI did use phonological strategies to a lesser extent than TH children to learn how to spell words.

Hence, to reach similar accuracy scores, DHH children probably used more orthographic information than TH children. This claim is supported by several lines of evidence. First, DHH children showed memorization of orthographic patterns in written production tasks (Aaron et al., 1998; Apel & Masterson, 2015; Quick et al., 2019). For instance, high-frequency patterns are sometimes used from one word to another (e.g., the bigram "th" or trigram "gth" as in "lauth" and "laugth" for *laugh*; or trigram "ght" as in "trght" for *truck*). Second, letter transposition errors (mostly adjacent letters) reflecting order errors in the recall of the letter position (e.g., "bule" or "beul" for *blue*) appeared to be overall higher in DHH children compared to TH children (Leybaert, 2000). Third, accuracy for irregular words, that is, words that cannot be spelled by phoneme–grapheme conversion rules but retrieved from memory, appeared to be as good in DHH as in TH children in their spelling (Bell et al., 2019) and better in DHH participants than TH in a recognition task (Hanson et al., 1983). DHH participants benefited more than TH ones from a visual presentation of stimuli in a recognition task compared to a written production task, notably for irregular words (Hanson et al., 1983), suggesting that DHH participants have memorized more orthographic information. Finally, studies by Miller and colleagues defend the idea that regardless of the spelling system (i.e., the complexity of phoneme–grapheme conversions), DHH children are as efficient as TH children in visual orthographic processing (Kargin et al., 2012; Miller, 2010; Miller & Clark, 2011). Importantly, all the results previously reported were found with real words.

Only recently has the construction of orthographic representations for new words has been investigated with the self-teaching paradigm in DHH children. Wass et al. (2019) compared English-speaking children with moderate-to-profound hearing loss, using hearing aids and/or CI, and TH children matched on chronological age (M_{age} = 9 years) and reading age. Participants had to read aloud eight stories, each containing a target pseudoword occurring 4 times. Target pseudowords consisted of four to six letters, with regular grapheme–phoneme mappings but inconsistent phoneme–grapheme correspondences. Stories were short (mean utterance = 27 words) and particularly explicit regarding the learning situation, such as: “The new word is [xxxx]. There is a hairy monster called a [xxxx]. The [xxxx] is very big. If you see [xxxx], you should run away” (p. 103), with [xxxx] as the target pseudoword. As in typical self-teaching paradigms, there was first an exposure phase, followed by two assessments of orthographic learning: a spelling-to-dictation task and a recognition task. In the recognition task, the target pseudoword (*laif*) was presented with a pseudohomophone of the target (*lafe*) and two visual distractors (*laip* and *lape*) that shared the same phonology to counteract potential choice decision strategies. Results showed that TH children were significantly better than DHH children for the spelling task, while no significant group difference was found in the recognition task. The larger difference between accuracy scores in spelling production and in orthographic recognition for the DHH children confirmed Hanson et al.’s (1983) findings. Moreover, there was a positive correlation between phonological decoding skills and the orthographic learning measures, in agreement with the self-teaching hypothesis (Share, 1995) and more generally with the role of phonological skills in spelling acquisition in DHH children.

Given the lack of research in orthographic learning in DHH children, further studies are necessary to understand the development and quality of orthographic representations. The present study used a self-teaching procedure to compare (a) how French-speaking DHH children and TH children build orthographic representations for words they read for the first time and (b) the quality of the orthographic representations newly created by analyzing the nature of spelling and recognition errors in the two groups. We expected both groups to reach higher performance in the recognition than in the spelling task and that the difference would be more important for DHH children. Regarding spelling errors, we predicted that DHH children would make less PPE than the TH children in the spelling task. In the recognition task, we predicted that DHH children would choose the phonological distractor less often in comparison to TH children. These predictions are based on the hypothesis that DHH children use phonological strategies to a lesser extent than TH children to learn how to spell words (Simon et al., 2019).

Method

Participants

Participants were recruited online due to COVID-19 restrictions, through mail and social media from associations, parents, or professionals working with children who are deaf. Initially, 31 children with moderate-to-profound hearing loss were enrolled in Belgium and France. Two participants were excluded, one because of a developmental spoken language disorder and the second because of noncomplete data, for a total of 29 children who are DHH. The group included 13 girls and 16 boys aged 7.8–13.5 years (M_{age} = 10.9). None of them had associated disorders such as neurological or intellectual disabilities (individual details are presented in Appendix A). One participant had single-side deafness, and four children had asymmetrical hearing loss. Ten out of the 29 participants were fitted with bilateral CIs, 13 wore bilateral hearing aids, and the other participants had at least one CI (*n* = 4) or a single hearing aid (*n* = 1) or did not use any devices at all (*n* = 1). Regarding communication modes, 27 DHH participants had hearing parents and were native speakers of French as a spoken language and two participants had deaf parents and only used French Sign Language at home.[2] Half of the children also used an additional communication mode: spoken French with cued

[2]These two factors could be possible reasons for excluding children from our sample due to variations in writing acquisition between oral and visual languages (Lederberg et al., 2019). Upon reanalyzing our data without the inclusion of these two participants, the outcomes remained unchanged. Consequently, these individuals were included in our final sample, acknowledging the inherent heterogeneity already existing within the group in terms of communication mode diversity.

speech (n = 5); spoken French with cued speech and French Sign Language (n = 3); Signed French (n = 4); and spoken French and French Sign Language (i.e., bimodal bilingualism, n = 2). The other half of the participants used spoken French only (n = 13). In terms of school education, 19 children attended regular schools with spoken French as the primary language. Most of them received additional support: Five had a cued speech transliterator, four had a teaching assistant, three benefited from both, and one had a sign language interpreter (sign language native child); six children attended regular schools without extra help. Six children were enrolled in specialized schools for the deaf. These institutions feature small classrooms composed entirely of DHH students, allowing for more individualized learning. The teachers have expertise in deaf education and tailor their instruction to each child's language preference. Furthermore, two children were enrolled in programs that enabled them to spend half of their time in specialized schools and the other half in regular schools. Finally, two children, including one native user of French Sign Language, joined bimodal bilingual classrooms (spoken French/French Sign Language) along with hearing children.

The control group consisted of 29 children with typical hearing, 14 girls and 15 boys, from 7.9 to 13.6 years old (M_{age} = 10.7). All the TH children attended regular schools in Belgium or France. The two groups were matched on age, gender, and education level (from Grade 2 to Grade 8). They were also matched on their visual word recognition abilities. To do so, the participants had to judge the lexicality of 20 words and 20 pseudowords appearing in a random order on the screen. The children had to decide as rapidly and as accurately as possible whether the stimuli were real words in French or not. To ensure that the two groups were matched, Cohen's d was calculated both on accuracy scores (d = 0.16) and reaction times (d = 0.01).

Material

Texts

Ten 45- to 55-word-long stories were created. Each story included one novel word (pseudoword), appearing 3 times. The position of the word within the three sentences varied among stories, and the stories were presented randomly. The story context was written so that the target pseudowords were "nouns" describing a tool, plant, object, means of transportation, or animal.

Target Pseudowords

The 10 targets were selected from a set of 52 invented pseudowords. Prior to data collection, 12 children with typical hearing listened to the 52 dictated pseudowords and were asked to type them. Pseudowords were presented randomly in an online survey. Each pseudoword was designed to include an inconsistent grapheme, taken from the LEXOP database (Peereman & Content, 1999). Based on the children's productions, we selected a final set of 10 items for which no child had written the target spelling. This way, we ensured that the spelling of target pseudowords was not predictable without learning. Item characteristics are detailed in Table 1.

Distractors for the Recognition Task

Three distractors were devised for each target pseudoword (e.g., *karmol*): a phonological distractor (e.g., *carmole*; pseudohomophone), an orthographic distractor (e.g., *kamrol*; visually similar to the target item), and a foil distractor (e.g., *camrole*; more distant from the target than the two others). Half of the orthographic distractors consisted of pseudowords with a letter transposition, for example, *karmol* transformed in *kamrol*; the other half were pseudowords with a visual letter substitution, for example, *tydomme* transformed in *lydomme*. Visual letter substitutions were based on the visual similarity matrix of

Table 1. Orthographic characteristics of the selected 10 target pseudowords.

Stimulus	Phonology	No. of letters	MLF	MBF	*N*	OLD20
phise	/fiz/	5	11071.98	834.91	2	1.9
gluète	/glyɛt/	6	4168.52	332.08	0	2.55
tydomme	/tidɔm/	7	2245.15	79.69	0	3.1
hiatré	/jatre/	6	3512.86	424.18	0	2.6
umèle	/ymɛl/	5	8233.03	667.04	0	2.05
triscat	/triska/	7	2272.03	290.64	0	2.95
blasc	/blask/	5	3451.30	204.35	3	1.85
neicle	/nɛkl/	6	5199.65	401.96	0	2.55
kouvice	/kuvis/	7	4305.71	681.92	0	2.95
karmol	/kaʁmɔl/	6	3718.50	671.20	0	2.65

Note. These scores are calculated from the Lexique database (http://www.lexique.org/). MLF = mean letter frequency (occurrence per million); MBF = mean bigram frequency (occurrence per million); *N* = number of orthographic neighbors; OLD20 = mean orthographic distance for a word to its 20 nearest orthographic neighbors.

Simpson et al. (2013). To control the phonological and orthographic proximity of the distractors to the target, we calculated for each item the phonological Levenshtein distance (PLD) and the orthographic Levenshtein distance (OLD), based on Yarkoni et al.'s (2008) metrics. Those scores account for each number of changes (insertions, deletions, substitutions, or transpositions) between one string of elements (phonemes or letters) from another. For instance, between *karmol* /karmɔl/ and *carmole* /karmɔl/ (phonological distractor), no difference in the phoneme string leads to PLD = 0, but two changes in the letter string leads to OLD = 2 (one letter substitution K ➔ C and one letter addition E). The orthographic distractor *kamrol* /kɑ̃rɔl/ has a PLD = 2 (due to the omission of the phoneme /m/ and the substitution of the phoneme /a/ into /ɑ̃/) and an OLD = 1 (one transposition of letters: *karmol* ➔ *kamrol*). The phonological distractor always had a PLD equal to zero since it was a pseudohomophone of the target. Thus, PLD of the phonological distractors (mean PLD = 0) was lower than the PLD of the other two distractors (mean PLD of the orthographic distractors = 1.2; mean PLD of the foil distractors = 1). The orthographic distractor always had an OLD (mean OLD = 1) lower than the OLD of the other two distractors (mean OLD of the phonological distractors = 2.2; mean OLD of the foil distractors = 2.8), so that orthography was as close as possible to that of the target. Whenever possible, the foil distractor was homophonic to the orthographic distractor to counteract adaptative decision strategies that might be used by the participants. Finally, the number of letters was matched between targets and distractors (see Appendix B).

Video Material for the Spelling Task

Traditionally, spelling dictation tasks have used audio inputs. However, the availability of audiovisual information (i.e., speech sounds coupled with lipreading) is known to enhance speech perception in TH and DHH adults and children (Erber, 1971; Sumby & Pollack, 1954), as well as in DHH children with CIs (Bergeson et al., 2005; Lachs et al., 2001). In our experiment, we therefore recorded video clips for target pseudowords to provide participants with audiovisual information. Videos were recorded in a quiet room, with a Sony HX60V camera. The pseudowords were pronounced by a female native Belgian French speaker. The speaker repeated each pseudoword 3 times, randomly presented. Only the best version of each pseudoword was selected, based on an evaluation by two independent judges. Thus, one video clip corresponded to one version of the pseudoword. A total of 10 video clips were created.

Procedure

Due to COVID-19 restrictions, the experiment was conducted online. At the beginning of the session, the experimenter conducted a videoconference with the parent(s) or a responsible adult (such as a speech therapist or learning support assistant) along with the child. The main purpose of this initial contact was to provide a summary of instructions and to switch off the automatic spell checker in the Internet browser. The experimenter also ensured that the child had all the material required for the experiment (a computer, a keyboard, and a mouse) and knew how to type, especially for letter keys with graphic accent such as "é" or "è." Once the child was ready, the experimenter sent a web link with the subject code. A first page with a summary of the instructions was read by the accompanying adult. The child agreement was asked by ticking a checkbox. Then, the child was autonomous throughout the experiment with the experimenter stayed available via videoconference if help was needed. The procedure followed a self-teaching paradigm, namely, an exposure phase (incidental orthographic learning phase), followed by two tasks assessing orthographic learning (a spelling task and a recognition task). Before each task, written instructions were given, except for the spelling task for which the instructions were provided with a subtitled video.[3]

During the exposure phase, the participants were told to read 10 stories and to be as attentive as possible, to be able to answer comprehension questions later. Each story was followed by a true/false question. The participants received feedback only for the training story. A break was offered after five stories. If the participant noticed the presence of the target item as an unknown word and asked the experimenter about its meaning, the experimenter would instruct the participant to keep reading to figure it out.

For the spelling task, the children were asked to type the word they heard from a video clip. Instructions were provided by a subtitled video which show the participant how to launch the video clip and type the pseudoword in a text box. Videos were presented one at a time on the computer screen, with a randomized presentation order between participants. Participants could watch the video as many times as needed.

The recognition task consisted of an orthographic choice task. Instructions were as follows: "Among these words, which one did you read in the story?" Four items appeared in random order on a horizontal line. The children had to click on one of them. In total, there were 10 items with four choices each time: the target pseudoword,

[3]The decision lexical task used for the participants matching (see the Participants section) was done at the end, after the self-teaching paradigm.

the phonological distractor, the orthographic distractor, and the foil distractor. Items were randomly shuffled.

Categorization of Errors in the Spelling and Recognition Task

In the spelling task, errors made by children were classified as PPE and PUE. This classification is based on Hayes et al. (2011) for English-speaking deaf children using a CI, replicated by Simon et al. (2019) for French. The PPE category included errors that were fully consistent with the phonological structure of a target word; the PUE included misspellings that were not consistent with the phonological structure of a word. Because the spelling task was computer based, the child could not move on to the next stimulus until he or she wrote something in the box. For this reason, we eliminated incoherent sequences of characters (e.g., “ggg”) or space characters that represented five responses over 261 from the data analysis (1.9% of the data). When errors could not be categorized in the two mentioned categories because they would be a lexical word (e.g., “simple” /sɛ̃pl/ for *tydomme* /tidɔm/) or pseudoword that did not match with orthographic or phonological elements of the target (e.g., “nakile” /nakil/ for *hiatré* /jatre/), we chose to assign them to an “Unclassified” error category. These cases appeared only in the group of deaf children for 14 spellings (5.5%). Unclassified errors were discarded from the statistical spelling error analysis. For the recognition task, error categories represent children’s choice of distractor over the target item: the phonological distractor, the orthographic distractor, and the foil distractor. Foil distractor responses (< 7%) were discarded from the statistical analysis as it is not relevant to infer the strategies used by children to build orthographic representations.

Statistical Analyses

A two-factor repeated-measures analysis of variance (ANOVA) was conducted to assess the effects of task (spelling, recognition), group (DHH, TH children), and the interaction between these two factors on accuracy. Regarding the quality of orthographic representations in DHH children in comparison to TH children, we used a Welch’s independent two-sample t test for both tasks on accuracy and we conducted a chi-square test of independence to analyze the nature of errors.

Results

The two-factor repeated-measures ANOVA showed a main effect of task, $F(1, 56) = 234.6$, $p < .001$, but no effect of group, $F(1, 56) = 1.33$, $p = .253$, indicating that the recognition task was easier than the spelling task for both groups. The interaction effect between task and group was statistically significant, $F(1, 56) = 8.97$, $p = .004$,[4] showing that the difference between the two tasks was larger for the DHH group than for the TH group.

Accuracy Analysis

In the spelling task, because of a technical issue from one of the video files (item: *kouvice*), the associated responses in both groups were discarded from the data analysis. Thus, a total of 261 spellings (29 participants × 9 items) for the group of TH children and 256 spellings (29 participants × 9 items, minus 5 nonanswered items) for the group of DHH children were analyzed for the spelling task. In this task, on average, 11% ($SD = 0.31$) of the spellings of DHH children were correctly spelled, and 13% ($SD = 0.34$) for TH children. There was no significant difference between the two groups, $t(56) = 0.86$, $p = .39$. In the recognition task, a total of 580 response were considered for the analysis (10 items × 29 participants × 2 groups). On average, 58% ($SD = 0.49$) of the choices made by DHH children were correct compared to 45% ($SD = 0.50$) for TH children. The scores in DHH children were significantly higher than in TH children, $t(56) = 3.09$, $p = .002$. Each group performed significantly above the chance level of 25%, $t(28) = 7.35$, $p < .001$ in DHH children and $t(28) = 4.67$, $p < .001$ in TH children.

Nature of Errors Analysis

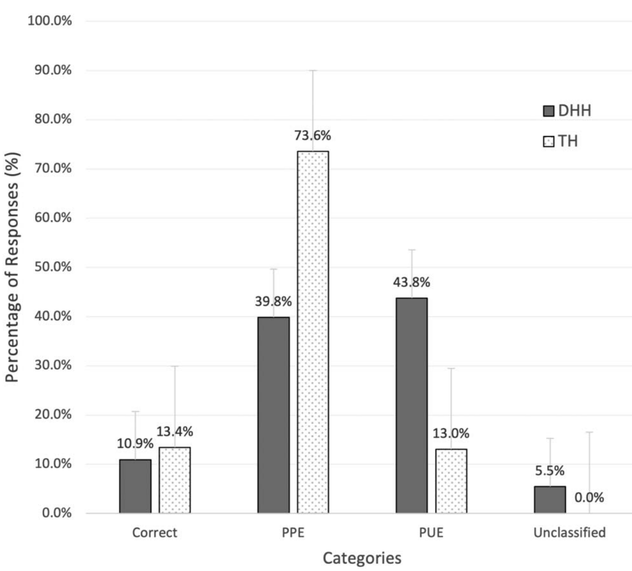
In each task, we used the Pearson’s chi-square test to compare the nature of spelling and recognition errors between the two groups. This statistical test measures the difference between observed and theoretical frequencies of categorical variables and enabled us to define whether the distribution of errors was group related.

In the spelling task, errors made by children were classified as PPE and PUE. Percentage of responses by category for DHH and TH children are illustrated in Figure 1.

Overall, the number of spelling errors was equivalent for both group (a total of 228 spelling errors for the DHH children and 226 spelling errors for the TH children). A chi-square test of independence was performed to examine the relation between the hearing status of children and the nature of errors they made. Results show a significant and strong association between the group and error distribution, $\chi^2(1) = 68.9$, $p < .001$, Cramer’s $V = 0.39$. In detail, DHH children made less PPE compared to TH children. Respectively, PPE (e.g., “blasque,” “blask,” or “blasck” /blask/ for *blasc* /blask/) represented 45% of

[4]The Task × Group interaction effect was also significant when z scores were used, $F(1, 56) = 9.33$, $p = .003$.

Figure 1. Percentage of responses by group and category in the spelling task. DHH = deaf and hard of hearing children; TH = typically hearing children; Correct = correct spellings; PPE = phonologically plausible error; PUE = phonologically unacceptable error; Unclassified = unclassified errors.



the spelling errors of the DHH group compared to 85% (n = 192 over 226; mostly "blasque" /blask/ for *blasc* /blask/) of the spelling errors of the TH group. Conversely, DHH children made more spelling errors with a change in the phonological structure than TH children. The PUE represented respectively 49% (n = 112; e.g., "blac" /blak/ or "blass" /blas/ for *blasc* /blask/) of the spelling errors for DHH children compared to 15% for TH children (n = 34; e.g., "blasce" /blas/ for *blasc* /blask/). A contingency table regrouping the number of PPE and PUE between the two groups is illustrated in Table 2 for the spelling task.

For the recognition task, error categories represent children's choice of distractor over the target item (see distractors details in the Material section). The percentage of responses by category of the orthographic choice task are illustrated in Figure 2 for each group of participants.

AQ7 **Table 2.** Contingency table of error categories in the spelling task.

Error category	Group		Total
	DHH	TH	
PPE	102	192	205
PUE	112	34	146
Total	214	226	440

Note. DHH = deaf and hard of hearing children; TH = typically hearing children; PPE = phonologically plausible error; PUE = phonologically unacceptable error.

Overall, DHH children made less recognition errors (n = 122) compared to TH children (n = 159). A chi-square test of independence was performed to examine the relationship between the hearing status of children and the nature of phonological or orthographic errors. Results show a significant association between the group and the error distribution, $\chi^2(1) = 10.3$, $p = .001$, Cramer's V = 0.21. In detail, DHH children made less phonological recognition errors compared to TH children. Quantitatively, phonologically recognition errors (e.g., "blasque" /blask/ for *blasc* /blask/) made by DHH children represented 59% of total errors and were fewer than among TH children (75% of total errors), while orthographic errors (e.g., "plasc" /plask/ for *blasc* /blask/) represented 26% of recognition errors in DHH children against 12% in TH children; see contingency in Table 3.

Discussion

The present study compared how French-speaking DHH children and TH children build orthographic representations for words they read for the first time. The stimuli were pseudowords with an inconsistent grapheme. The two groups were matched for reading level and chronological age. The DHH children group was heterogenous regarding the type of hearing devices and the communication mode used at home. The quality of newly created orthographic representations was assessed by two tasks: a spelling production task and a recognition task, requesting

Figure 2. Percentage of response by group and category in the recognition task. DHH = deaf and hard of hearing children; TH = typically hearing children.

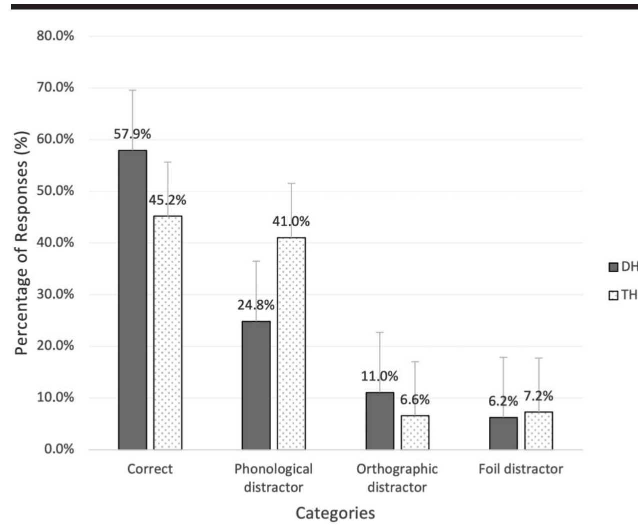


Table 3. Contingency table of error categories in the orthographic choice task.

Error category	Group		Total
	DHH	TH	
Phonological distractor	72	119	191
Orthographic distractor	32	19	51
Total	104	138	242

Note. DHH = deaf and hard of hearing children; TH = typically hearing children.

the choice between correct response, phonological distractor, and orthographic distractor. Overall, we expected both groups to reach higher performance in the recognition than in the spelling task, with a more important difference for DHH children. Since we used pseudowords as novel words, the reading and spelling processes involved a phonological recoding process. Phonological strategies in spelling are used to a lesser extent by DHH children than TH children (e.g., Simon et al., 2019, for French data). Consequently, we predicted that DHH children would make less PPE than the TH children in the spelling task and that DHH children would choose the phonological distractor less often in comparison to TH children in the recognition task.

To understand the strategies used by DHH children to create new orthographic representations, we relied on the self-teaching hypothesis (Share, 1995, 1999). According to this hypothesis, children autonomously encounter and decode unfamiliar orthographic forms in reading by means of grapheme–phoneme conversion rules. Pseudowords are generally used as targets (acting as novel words) to ensure that no prior lexical information is used in the build-up of orthographic representations (see Li & Wang, 2023, for details). Overall, new orthographic representations are mainly based on children's decoding skills (Bowey & Muller, 2005; Cunningham et al., 2002; Share, 1995, 1999), but orthographic knowledge from print experience also plays a role (Bosse et al., 2015; Nation et al., 2007).

In the present study, as expected, both groups performed higher in the recognition task than in the spelling task. Recognition requires less cognitive effort than spelling, as for the latter, orthographic representations need to be complete and accurate (Ehri & Saltmarsh, 1995). In our results, the difference in performance between the spelling and the recognition tasks was more important in DHH children than in TH children. This interaction also reported in Hanson et al. (1983) for real words in deaf adults suggested that the visual presentation of alternative spellings might better help DHH participants. Overall, we can say that both groups acquire the capacity to create sufficiently detailed new orthographic representations to recognize the target item among distractors, which supports the self-teaching hypothesis of autonomous orthographic learning from reading (Share, 1995).

We will first discuss the results of the spelling task and next those of the recognition task. Data in the spelling task indicate that both groups achieved low accuracy, suggesting that the children did not acquire complete and detailed enough orthographic representations after three exposures to the novel words. The lack of significant difference between groups can be due to a floor effect (correct responses reached 11% for DHH children and 13% for TH children). However, this lack of evidence for a difference does not mean that no learning happened. Indeed, even if the entire spelling of the words was not well encoded by the participants after three exposures, the memorization of partial orthographic information allowed the children to recognize the targets above chance level.

In other self-teaching studies, spelling accuracy scores were higher (e.g., 70% in Cunningham et al., 2002; 36% in Cunningham, 2006; 52% and 39% in Share, 1999; and about 50% in Wass et al., 2019). Four factors may be involved. First, in most of these studies, participants were exposed to one or the other version of two pseudohomophones (e.g., *yait/yate* in Cunningham et al., 2002) for which no prior control had been made regarding their spelling predictability before exposure. For example, Smejkalova and Chetail (2023) reported that spontaneous written productions that matched target spellings for nonexposed pseudowords reached 7%. Consequently, self-teaching studies that did not consider spontaneous spelling scores as the learning baseline may have led to overestimated learning scores (Smejkalova & Chetail, 2023). Second, the low scores in our spelling task could be the result of the French spelling system itself. Indeed, French is considered harder to spell than to read (Peereman & Content, 1999). French spellers take more time and make more errors when spelling inconsistent words than consistent words (Fayol et al., 2008). Spelling of pseudowords that contained inconsistencies could have taken more time to be memorized. Third, the number of exposures to the pseudowords could have an impact. For example, only one exposure can be enough for orthographic learning whether in a consistent (Share, 1999, for Hebrew) or inconsistent (Nation et al., 2007, for English) spelling system. However, Nation and colleagues reported better learning for items that were seen more often, "demonstrating that learning is frequency sensitive" (p. 83). In our case, it seems that for both groups, retrieving the whole spelling of the pseudoword after three exposures was not sufficient to spell it correctly. Fourth, the assessment phase took place after the entire exposure phase to the 10 pseudowords in our experiment, in line with most self-teaching studies for TH children (Li & Wang, 2023). In the study of Wass et al. (2019), orthographic learning was assessed in the middle of the exposure phase (after four stories over eight in total for the session). In addition, each story began with a more explicit context of learning ("The new word is ___") than in our study (incidental context). These two points potentially triggered children to adopt working memory strategies (Cowan, 2010; Repovš & Baddeley, 2006) to store the new words knowing the goal of the assessment. Our study was not specifically designed to make theoretical distinctions regarding working memory processes, which further research would investigate.

Despite no significant difference in spelling accuracy, the nature of errors varied significantly between the two groups. As expected, DHH children made less PPE (40%) than TH children (74%). These results are comparable to those of Hayes et al. (2011) and Simon et al. (2019). By contrast, the high percentage of PUE in DHH children (44%) is compatible with three main interpretations. First, the DHH participants might have encoded less specified phonological representations during reading, which is in line with previous reports of lower phonological decoding skills in DHH children (Dyer et al., 2003; Perfetti & Sandak, 2000) or decreased sensitivity to phonological cues in skilled deaf adult readers (Costello et al., 2021). In our spelling task, the pseudowords presented through an audio–visual presentation might not activate the underspecified phonological representation memorized during the exposure phase (even if the instructions explicitly informed the children that the words they heard were those from the stories they just read). This hypothesis might be true for some of our participants, but not for others, as some DHH children appear to be on average within the norm of TH children with respect to decoding skills, despite a large variability (Couvee et al., 2023; Mathews & O'Donnell, 2020). Second, the DHH children might have misperceived the stimuli delivered in audio–visual format. Indeed, some of the exclusively found PUE were in line with the speech perception errors in DHH children, even with CIs (Grandon, 2016; Machart, 2022). For instance, *tarmol* was produced instead of "karmol" (variation of the place of articulation). Third, the high percentage of PUE errors in DHH children could also suggest that nonphonological strategies were used to memorize the new orthographic representations. Especially, transposition errors (e.g., *ihatré* produced instead of *hiatré*) suggest that the children correctly memorized the identity of letters of the new words. However, the use of such a visual–orthographic strategy is difficult to establish from our data because transposition errors were rare (seven in DHH children vs. three in TH children; see also Hoemann et al., 1976). In summary, in the present data, most of the orthographic errors are also phonological in nature and thus difficult to interpret (Perfetti & Sandak, 2000). It thus seems that DHH children use a mix of strategies, with less weight placed on a phonological strategy than by TH children. The results in the recognition task might shed light on this issue since the two strategies were considered in the creation of the distractors.

Interestingly, the results in the recognition task indicate a significant difference between groups: DHH children reached a higher percentage of correct responses (58%) than TH children (45%). However, before interpreting this result, a discussion of the errors might be important: Considering the nature of errors in the recognition task, "phonological distractor" was the first category of errors for both groups, which suggests that phonological strategies were primarily used by both DHH and TH children. Indeed, if children had mostly relied on phonological process to create new orthographic representations, they would have chosen the target or the phonological distractor arbitrarily. This is the case in TH children (45% of correct responses vs. 41% of phonological distractor choice). In DHH children, however, the difference between these two categories is much more marked, as the number of correct responses (58%) represents more than twice the phonological distractor choice (25%). Therefore, these data suggest that DHH children are less influenced by the phonological cues of new words when building new orthographic representations.

Moreover, a strong association between the group and the error distribution was found, also suggesting a difference in the memorization process. Quantitatively, phonologically recognition errors made by DHH children (59% of total errors) were lower than in TH children (75% of total errors), while orthographic errors represented 26% of total errors in DHH children against 12% in TH children. This finding suggests that the DHH group probably has an advantage in using the orthographic information. Our results are in line with those of Hanson et al. (1983), who found that skilled DHH readers showed a better recognition score than TH readers for irregular words for which the spelling could not be generated by a pure phonological strategy.

Beyond considering the quantitative differences between DHH and TH groups, it might be interesting to discuss potential sources of variability inside our DHH group. Language differences might impact orthographic learning strategies as phonological awareness is not based on the same units whether children were raised in a spoken or signed language environment (Lederberg et al., 2019). In our study, two children learned spelling in a bimodal spoken French and French sign language context, and other children attended schools (mainstreamed and specialized) where spoken French was the teaching language, whether with cued speech or not. Considering the small number of DHH children in our study, future research should investigate the impact of communication modes on orthographic learning strategies as a function of DHH children's profiles.

To conclude, orthographic learning in DHH children has been studied for written English only once. The present study adds information on how orthographic representations develop in DHH children with a French written language background. We showed first that a self-teaching mechanism is present in DHH children; second, that phonology plays a role in this learning; and third, that the strategies used by DHH children are more orthographically oriented than in TH children. Future investigations using the self-teaching paradigm with DHH children should overcome the limitation represented by the very low scores in the spelling task. Possible ways to increase spelling accuracy are increasing the number of exposures (see Nation et al., 2007) or assessing the new orthographic representations not through audio–visual input only but also by adding semantic information such as a picture of the new word (Wang et al., 2011). Finally, the present study showed that using a spelling task and a recognition task in combination and analyzing the nature of errors generated in both tasks provide a reliable methodological way to understand the underlying cognitive processes of orthographic learning and should be implemented more often for clinical purposes. Methods of teaching reading or spelling should consider the variability of phonological skills acquired by DHH children. Teaching methods should not underestimate the impact of visual input when DHH children learn to spell, as it seems to be important in learning and recognizing (new) orthographic representations.

Data Availability Statement

Analyses were run with the R software (Version 4.1.1; R Core Team, 2021) under the RStudio environment (RStudio Team, 2020). Raw data and scripts for analyses are available at https://osf.io/8neut/.

Institutional Review Board Statement

This study was conducted in accord with American Psychological Association standards for ethical treatment of participants and with the approval of the university's institutional review board.

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References

Aaron, P. G., Keetay, V., Boyd, M., Palmatier, S., & Wacks, J. (1998). Spelling without phonology: A study of deaf and hearing children. *Reading and Writing, 10*(1), 1–22. https://doi.org/10.1023/A:1007917929226

Alegria, J. (1998). The origin and functions of phonological representations in deaf people. In C. Hulme & R. M. Joshi (Eds.), *Reading and spelling: Development and disorders* (Vol. 1, pp. 263–286). Lawrence Erlbaum Associates, Inc.

Apel, K., & Masterson, J. J. (2015). Comparing the spelling and reading abilities of students with cochlear implants and students with typical hearing. *Journal of Deaf Studies and Deaf Education, 20*(2), 125–135. https://doi.org/10.1093/deafed/env002

Bell, N., Angwin, A. J., Wilson, W. J., & Arnott, W. L. (2019). Spelling in children with cochlear implants: Evidence of underlying processing differences. *Journal of Deaf Studies and Deaf Education, 24*(2), 161–172. https://doi.org/10.1093/deafed/eny035

Bergeson, T. R., Pisoni, D. B., & Davis, R. A. O. (2005). Development of audiovisual comprehension skills in prelingually deaf children with cochlear implants. *Ear and Hearing, 26*(2), 149–164. https://doi.org/10.1097/00003446-200504000-00004

Bosse, M.-L., Chaves, N., Largy, P., & Valdois, S. (2015). Orthographic learning during reading: The role of whole-word visual processing. *Journal of Research in Reading, 38*(2), 141–158. https://doi.org/10.1111/j.1467-9817.2012.01551.x

Bowey, J. A., & Muller, D. (2005). Phonological recoding and rapid orthographic learning in third-graders' silent reading: A critical test of the self-teaching hypothesis. *Journal of Experimental Child Psychology, 92*(3), 203–219. https://doi.org/10.1016/j.jecp.2005.06.005

Cassar, M., & Treiman, R. (1997). The beginnings of orthographic knowledge: Children's knowledge of double letters in words. *Journal of Educational Psychology, 89*(4), 631–644. https://doi.org/10.1037/0022-0663.89.4.631

Colin, S., Leybaert, J., Ecalle, J., & Magnan, A. (2013). The development of word recognition, sentence comprehension, word spelling, and vocabulary in children with deafness: A longitudinal study. *Research in Developmental Disabilities, 34*(5), 1781–1793. https://doi.org/10.1016/j.ridd.2013.02.001

Colin, S., Magnan, A., Ecalle, J., & Leybaert, J. (2007). Relation between deaf children's phonological skills in kindergarten and word recognition performance in first grade. *Journal of Child Psychology and Psychiatry, 48*(2), 139–146. https://doi.org/10.1111/j.1469-7610.2006.01700.x

Coltheart, M., Curtis, B., Atkins, P., & Haller, M. (1993). Models of reading aloud: Dual-route and parallel-distributed-processing approaches. *Psychological Review, 100*(4), 589–608. https://doi.org/10.1037/0033-295X.100.4.589

Cornett, R. O. (1967). Cued speech. *American Annals of the Deaf, 112*(1), 3–13.

Costello, B., Caffarra, S., Fariña, N., Duñabeitia, J. A., & Carreiras, M. (2021). Reading without phonology: ERP evidence from skilled deaf readers of Spanish. *Scientific Reports, 11*(1), Article 5202. https://doi.org/10.1038/s41598-021-84490-5

Couvee, S., Wauters, L., Knoors, H., Verhoeven, L., & Segers, E. (2023). Predicting variation in word decoding development in deaf and hard-of-hearing children. *Reading and Writing*. Advance online publication. https://doi.org/10.1007/s11145-023-10444-0

Cowan, N. (2010). The magical mystery four: How is working memory capacity limited, and why? *Current Directions in Psychological Science, 19*(1), 51–57. https://doi.org/10.1177/0963721409359277

Cunningham, A. E. (2006). Accounting for children's orthographic learning while reading text: Do children self-teach? *Journal of Experimental Child Psychology, 95*(1), 56–77. https://doi.org/10.1016/j.jecp.2006.03.008

Cunningham, A. E., Perry, K., Stanovich, K., & Share, D. (2002). Orthographic learning during reading: Examining the role of self-teaching. *Journal of Experimental Child Psychology, 82*(3), 185–199. https://doi.org/10.1016/S0022-0965(02)00008-5

de Jong, P. F., Bitter, D. J. L., Van Setten, M., & Marinus, E. (2009). Does phonological recoding occur during silent reading, and is it necessary for orthographic learning? *Journal of Experimental Child Psychology, 104*(3), 267–282. https://doi.org/10.1016/j.jecp.2009.06.002

Dodd, B. (1976). The phonological systems of deaf children. *Journal of Speech and Hearing Disorders, 41*(2), 185–198. https://doi.org/10.1044/jshd.4102.185

Dyer, A., MacSweeney, M., Szczerbinski, M., Green, L., & Campbell, R. (2003). Predictors of reading delay in deaf adolescents: The relative contributions of rapid automatized naming speed and phonological awareness and decoding. *Journal of Deaf Studies and Deaf Education, 8*(3), 215–229. https://doi.org/10.1093/deafed/eng012

Ehri, L. C. (1995). Phases of development in learning to read words by sight. *Journal of Research in Reading, 18*(2), 116–125. https://doi.org/10.1111/j.1467-9817.1995.tb00077.x

Ehri, L. C. (2000). Learning to read and learning to spell: Two sides of a coin. *Topics in Language Disorders, 20*(3), 19–36. https://doi.org/10.1097/00011363-200020030-00005

Ehri, L. C. (2005). Learning to read words: Theory, findings, and issues. *Scientific Studies of Reading, 9*(2), 167–188. https://doi.org/10.1207/s1532799xssr0902_4

Ehri, L. C., & Saltmarsh, J. (1995). Beginning readers outperform older disabled readers in learning to read words by sight. *Reading and Writing: An Interdisciplinary Journal, 7*(3), 295–326. https://doi.org/10.1007/BF03162082

Erber, N. P. (1971). Auditory and audiovisual reception of words in low-frequency noise by children with normal hearing and by children with impaired hearing. *Journal of Speech and Hearing Research, 14*(3), 496–512. https://doi.org/10.1044/jshr.1403.496

Fayol, M., Bonin, P., & Collay, S. (2008). La consistance orthographique en production verbale écrite: Une brève synthèse. *L'Année psychologique, 108*(03), 517–546. https://doi.org/10.4074/S0003503308003059

Frith, U. (1985). Beneath the surface of developmental dyslexia. In K. Patterson, J. C. Marshall, & M. Coltheart (Eds.), *Surface dyslexia: Neuropsychological and cognitive studies of phonological reading* (1st ed., pp. 301–330). Routledge. https://doi.org/10.4324/9781315108346

Grandon, B. (2016). *Développement typique et atypique de la production de parole: Caractéristiques segmentales et intelligibilité de la parole d'enfants porteurs d'un implant cochléaire et d'en-fants normo-entendants de 5 à 11 ans* [Doctoral thesis, Université Grenoble Alpes (ComUE)]. https://www.theses.fr/2016GREAL029

Grantham, H. (2020). Spelling: Why explicit instruction is a critical component of literacy intervention for children who are deaf or hard of hearing. In S. R. Easterbrooks & H. M. Dostal (Eds.), *The Oxford handbook of deaf studies in literacy* (pp. 296–307). Oxford University Press. https://doi.org/10.1093/oxfordhb/9780197508268.013.21

Hanson, V.L., Shankweiler, D., & Fisher, FW. (1983). Determinants of spelling ability in deaf and hearing adults: Access to linguistic structure. *Cognition,* 14(3), 323-344. https://doi.org/10.1016/0010-0277(83)90009-4

Harris, M., & Moreno, C. (2004). Deaf children's use of phonological coding: Evidence from reading, spelling, and working memory. *The Journal of Deaf Studies and Deaf Education, 9*(3), 253–268. https://doi.org/10.1093/deafed/enh016

Harris, M., & Terlektsi, E. (2011). Reading and spelling abilities of deaf adolescents with cochlear implants and hearing aids. *Journal of Deaf Studies and Deaf Education, 16*(1), 24–34. https://doi.org/10.1093/deafed/enq031

Hayes, H., Kessler, B., & Treiman, R. (2011). Spelling of deaf children who use cochlear implants. *Scientific Studies of Reading, 15*(6), 522–540. https://doi.org/10.1080/10888438.2010.528480

Herman, R., Roy, P., & Kyle, F. E. (2017). *Reading and dyslexia in deaf children* [Report]. Nuffield Foundation; City University London. https://openaccess.city.ac.uk/id/eprint/18544/

Hoemann, H. W., Andrews, C. E., Florian, V. A., Hoemann, S. A., & Jensema, C. J. (1976). The spelling proficiency of deaf children. *American Annals of the Deaf, 121*(5), 489–493.

Kargin, T., Guldenoglu, B., Miller, P., Hauser, P., Rathman, C., Kubus, O., & Spurgeon, E. (2012). Differences in word processing skills of deaf and hearing individuals reading in different orthographies. *Journal of Developmental and Physical Disabilities, 24*(1), 65–83. https://doi.org/10.1007/s10882-011-9255-z

Kessler, B., Pollo, T. C., Treiman, R., & Cardoso-Martins, C. (2013). Frequency analyses of prephonological spellings as predictors of success in conventional spelling. *Journal of Learning Disabilities, 46*(3), 252–259. https://doi.org/10.1177/0022219412449440

Kyle, F. E., & Harris, M. (2006). Concurrent correlates and predictors of reading and spelling achievement in deaf and hearing school children. *The Journal of Deaf Studies and Deaf Education, 11*(3), 273–288. https://doi.org/10.1093/deafed/enj037

Kyle, F. E., & Harris, M. (2011). Longitudinal patterns of emerging literacy in beginning deaf and hearing readers. *The Journal of Deaf Studies and Deaf Education, 16*(3), 289–304. https://doi.org/10.1093/deafed/enq069

Lachs, L., Pisoni, D. B., & Kirk, K. I. (2001). Use of audiovisual information in speech perception by prelingually deaf children with cochlear implants: A first report. *Ear and Hearing, 22*(3), 236–251. https://doi.org/10.1097/00003446-200106000-00007

Lederberg, A. R., Branum-Martin, L., Webb, M., Schick, B., Antia, S., Easterbrooks, S. R., & Connor, C. M. (2019). Modality and interrelations among language, reading, spoken phonological awareness, and fingerspelling. *The Journal of Deaf Studies and Deaf Education, 24*(4), 408–423. https://doi.org/10.1093/deafed/enz011

Leybaert, J. (2000). Phonology acquired through the eyes and spelling in deaf children. *Journal of Experimental Child Psychology, 75*(4), 291–318. https://doi.org/10.1006/jecp.1999.2539

Leybaert, J., & Alegria, J. (1995). Spelling development in deaf and hearing children: Evidence for use of morpho-phonological regularities in French. *Reading and Writing, 7*(1), 89–109. https://doi.org/10.1007/BF01026949

Leybaert, J., & Lechat, J. (2001). Variability in deaf children's spelling: The effect of language experience. *Journal of Educational Psychology, 93*(3), 554–562. https://doi.org/10.1037/0022-0663.93.3.554

Li, Y., & Wang, M. (2023). A systematic review of orthographic learning via self-teaching. *Educational Psychologist, 58*(1), 35–56. https://doi.org/10.1080/00461520.2022.2137673

Lorenzi, C., Gilbert, G., Carn, H., Garnier, S., & Moore, B. C. J. (2006). Speech perception problems of the hearing impaired reflect inability to use temporal fine structure. *Proceedings of the National Academy of Sciences of the United States of America, 103*(49), 18866–18869. https://doi.org/10.1073/pnas.0607364103

Machart, L. (2022). *Production de parole chez l'enfant sourd: Bénéfices de l'exposition à la Langue française Parlée Complétée associée à l'implantation cochléaire* [Doctoral thesis, Université Grenoble Alpes]. https://www.theses.fr/2022GRALS030

Mathews, E. S., & O'Donnell, M. (2020). Phonological decoding and reading comprehension in deaf and hard-of-hearing children. *European Journal of Special Needs Education, 35*(2), 220–235. https://doi.org/10.1080/08856257.2019.1646954

Mayer, C., & Trezek, B. J. (2018). Literacy outcomes in deaf students with cochlear implants: Current state of the knowledge. *The Journal of Deaf Studies and Deaf Education, 23*(1), 1–16. https://doi.org/10.1093/deafed/enx043

Miller, P. (2010). Phonological, orthographic, and syntactic awareness and their relation to reading comprehension in prelingually deaf individuals: What can we learn from skilled readers? *Journal of Developmental and Physical Disabilities, 22*(6), 549–580. https://doi.org/10.1007/s10882-010-9195-z

Miller, P., & Clark, M. D. (2011). Phonemic awareness is not necessary to become a skilled deaf reader. *Journal of Developmental and Physical Disabilities, 23*(5), 459–476. https://doi.org/10.1007/s10882-011-9246-0

Naik, A. N., Varadarajan, V. V., & Malhotra, P. S. (2021). Early pediatric cochlear implantation: An update. *Laryngoscope Investigative Otolaryngology, 6*(3), 512–521. https://doi.org/10.1002/lio2.574

Nation, K., Angell, P., & Castles, A. (2007). Orthographic learning via self-teaching in children learning to read English: Effects of exposure, durability, and context. *Journal of Experimental Child Psychology, 96*(1), 71–84. https://doi.org/10.1016/j.jecp.2006.06.004

Pacton, S., Borchardt, G., Treiman, R., Lété, B., & Fayol, M. (2014). Learning to spell from reading: General knowledge about spelling patterns influences memory for specific words. *Quarterly Journal of Experimental Psychology, 67*(5), 1019–1036. https://doi.org/10.1080/17470218.2013.846392

Pacton, S., Fayol, M., & Perruchet, P. (2002). The acquisition of untaught orthographic regularities in French. In L. Verhoeven, C. Elbro, & P. Reitsma (Eds.), *Precursors of functional literacy* (pp. 121–137). John Benjamins Publishing Company. https://doi.org/10.1075/swll.11.11pac

Peereman, R., & Content, A. (1999). LEXOP: A lexical database providing orthography–phonology statistics for French monosyllabic words. *Behavior Research Methods, Instruments, & Computers, 31*(2), 376–379. https://doi.org/10.3758/bf03207735

Peereman, R., Lété, B., & Sprenger-Charolles, L. (2007). Manulex-infra: Distributional characteristics of grapheme—Phoneme mappings, and infralexical and lexical units in child-directed written material. *Behavior Research Methods, 39*(3), 579–589. https://doi.org/10.3758/BF03193029

Perfetti, C. A., & Sandak, R. (2000). Reading optimally builds on spoken language: Implications for deaf readers. *Journal of Deaf Studies and Deaf Education, 5*(1), 32–50. https://doi.org/10.1093/deafed/5.1.32

Pisoni, D. B. (2008). Speech perception in deaf children with cochlear implants. In D. B. Pisoni & R. E. Remez (Eds.), *The handbook of speech perception* (pp. 494–523). Blackwell Publishing.

Quick, N., Harrison, M., & Erickson, K. (2019). A multilinguistic analysis of spelling among children with cochlear implants. *The Journal of Deaf Studies and Deaf Education, 24*(1), 41–53. https://doi.org/10.1093/deafed/eny029

R Core Team. (2021). *R: A ;anguage and environment for statistical computing* [Computer software]. R Foundation for Statistical Computing. https://www.R-project.org/

Rees, R., & Bladel, J. (2013). Effects of English cued speech on speech perception, phonological awareness and literacy: A case study of a 9-year-old deaf boy using a cochlear implant. *Deafness & Education International, 15*(4), 182–200. https://doi.org/10.1179/1557069X13Y.0000000025

Repovš, G., & Baddeley, A. (2006). The multi-component model of working memory: Explorations in experimental cognitive psychology. *Neuroscience, 139*(1), 5–21. https://doi.org/10.1016/j.neuroscience.2005.12.061

Roy, P., Shergold, Z., Kyle, F. E., & Herman, R. (2015). Spelling in oral deaf and hearing dyslexic children: A comparison of phonologically plausible errors. *Research in Developmental Disabilities, 36,* 277–290. https://doi.org/10.1016/j.ridd.2014.10.012

RStudio Team. (2020). *RStudio: Integrated development environment for R* [Computer software]. RStudio, PBC. http://www.rstudio.com/

Seymour, P. H. K., Aro, M., & Erskine, J. M. (2003). Foundation literacy acquisition in European orthographies. *British Journal of Psychology, 94*(2), 143–174. https://doi.org/10.1348/000712603321661859

Share, D. L. (1995). Phonological recoding and self-teaching: Sine qua non of reading acquisition. *Cognition, 55*(2), 151–218. https://doi.org/10.1016/0010-0277(94)00645-2

Share, D. L. (1999). Phonological recoding and orthographic learning: A direct test of the self-teaching hypothesis. *Journal of Experimental Child Psychology, 72*(2), 95–129. https://doi.org/10.1006/jecp.1998.2481

Share, D. L. (2004). Orthographic learning at a glance: On the time course and developmental onset of self-teaching. *Journal of Experimental Child Psychology, 87*(4), 267–298. https://doi.org/10.1016/j.jecp.2004.01.001

Simon, M., Fromont, L. A., Le Normand, M.-T., & Leybaert, J. (2019). Spelling, reading abilities and speech perception in deaf children with a cochlear implant. *Scientific Studies of Reading, 23*(6), 494–508. https://doi.org/10.1080/10888438.2019.1613407

Simpson, I. C., Mousikou, P., Montoya, J. M., & Defior, S. (2013). A letter visual-similarity matrix for Latin-based alphabets. *Behavior Research Methods, 45*(2), 431–439. https://doi.org/10.3758/s13428-012-0271-4

Smejkalova, A., & Chetail, F. (2023). Learning new words by reading books: Does semantic information help? *Quarterly Journal of Experimental Psychology, 76*(3), 568–582. https://doi.org/10.1177/17470218221095735

Sprenger-Charolles, L., Siegel, L. S., & Bonnet, P. (1998). Reading and spelling acquisition in French: The role of phonological mediation and orthographic factors. *Journal of Experimental Child Psychology, 68*(2), 134–165. https://doi.org/10.1006/jecp.1997.2422

Sumby, W. H., & Pollack, I. (1954). Visual contribution to speech intelligibility in noise. *The Journal of the Acoustical Society of America, 26*(2), 212–215. https://doi.org/10.1121/1.1907309

Tamura, N., Castles, A., & Nation, K. (2017). Orthographic learning, fast and slow: Lexical competition effects reveal the time course of word learning in developing readers. *Cognition, 163,* 93–102. https://doi.org/10.1016/j.cognition.2017.03.002

Treiman, R. (2017). Learning to spell: Phonology and beyond. *Cognitive Neuropsychology, 34*(3–4), 83–93. https://doi.org/10.1080/02643294.2017.1337630

Treiman, R., & Yin, L. (2011). Early differentiation between drawing and writing in Chinese children. *Journal of Experimental Child Psychology, 108*(4), Article 786. https://doi.org/10.1016/j.jecp.2010.08.013, 801.
Véronis, J. (1988). From sound to spelling in French: Simulation on a computer. *Cahiers de Psychologie Cognitive, 8*(4), 315–334.
Wang, H.-C., Castles, A., Nickels, L., & Nation, K. (2011). Context effects on orthographic learning of regular and irregular words. *Journal of Experimental Child Psychology, 109*(1), 39–57. https://doi.org/10.1016/j.jecp.2010.11.005
Wang, H.-C., Wass, M., & Castles, A. (2017). Paired-associate learning ability accounts for unique variance in orthographic learning. *Scientific Studies of Reading, 21*(1), 5–16. https://doi.org/10.1080/10888438.2016.1231686
Wass, M., Ching, T. Y. C., Cupples, L., Wang, H.-C., Lyxell, B., Martin, L., Button, L., Gunnourie, M., Boisvert, I., McMahon, C., & Castles, A. (2019). Orthographic learning in children who are deaf or hard of hearing. *Language, Speech, and Hearing Services in Schools, 50*(1), 99–112. https://doi.org/10.1044/2018_LSHSS-17-0146
Yarkoni, T., Balota, D., & Yap, M. (2008). Moving beyond Coltheart's *N*: A new measure of orthographic similarity. *Psychonomic Bulletin & Review, 15*(5), 971–979. https://doi.org/10.3758/PBR.15.5.971
Ziegler, J. C., Jacobs, A. M., & Stone, G. O. (1996). Statistical analysis of the bidirectional inconsistency of spelling and sound in French. *Behavior Research Methods, Instruments & Computers, 28*(4), 504–515. https://doi.org/10.3758/BF03200539

Appendix A

Individual Characteristics of Children Who Are Deaf and Hard of Hearing

ID	Sex	Age	Grade	Type of hearing loss	HA	CI	Age at HA/CI	Communication mode
P01	F	12.7	7th	Acquired	2		86	Oral only
P02	M	11.7	6th	Unknown	2		25	Oral with CS and punctual signs
P03	M	12.2	7th	Congenital		1	15	Oral with CS
P04	M	13.4	7th	Congenital	2		23	Oral with CS
P05	M	8.8	3rd	Congenital		2	11; 21	Oral with CS and 2nd spoken language
P06	M	10.0	4th	Congenital		2	12	Oral only
P07	F	12.6	7th	Congenital			NA	SL only
P08	M	10.9	5th	Unknown	2		18	Oral only
P09	M	12.4	6th	Acquired	1	1	96; 14	Oral and punctual signs
P10	F	9.7	5th	Congenital		2	30; 60	Oral with CS and SL
P11	M	9.8	4th	SSD acquired	2		3	Oral only
P12	F	12.1	6th	Congenital		2	30; 36	Oral with CS
P13	M	11.0	5th	Congenital	2		72	Oral only
P14	F	12.8	7th	Congenital	2		3	Oral only
P15	M	12.4	5th	Congenital	2		48	Oral only
P16	F	12.1	5th	Acquired	1	1	48; 128	Oral only
P17	F	13.5	8th	Congenital	1		6	Oral and punctual signs
P18	M	10.2	3rd	Congenital		2	28	Oral and punctual signs
P19	M	10.8	4th	Acquired	2		94	Oral only
P20	F	11.5	4th	Congenital	2		48	Oral and SL
P21	F	10.4	4th	Congenital	1	1	17; 57	Oral with CS and SL
P22	F	10.6	3rd	Congenital		2	24	Oral, SL, and 2nd spoken language
P23	F	8.3	2nd	Congenital	2		36	Oral only
P24	M	10.4	3rd	Congenital		2	15; 34	Oral only
P25	F	8.1	2nd	Congenital		2	23; 27	Oral only
P26	M	11.0	5th	Congenital		2	15; 30	Oral with CS
P27	M	8.8	3rd	Congenital	2		8	Oral only
P28	M	7.8	2nd	Congenital		2	10; 17	Oral with CS and SL
P29	F	10.1	4th	Congenital	2		8	SL only

Note. HA = hearing aid; CI = cochlear implant; F = female; M = male; CS = cued speech; SL = sign language; SSD = single-side deafness; NA = not applicable.

Appendix B

Target Items and Associated Distractors in the Recognition Task

Item	Target	Phonological distractor	Orthographical distractor	Foil distractor
Stimuli	phise	fise	plise	tise
No. of letters	5	4	5	4
PLD	—	0	2	1
OLD	—	2	1	2
Stimuli	gluète	gluette	gulète	gulette
No. of letters	6	7	6	7
PLD	—	0	1	1
OLD	—	2	1	3
Stimuli	tydomme	tidome	lydomme	lidome
No. of letters	7	6	7	6
PLD	—	0	1	1
OLD	—	2	1	3
Stimuli	hiatré	yatré	hiarté	yarté
No. of letters	6	5	6	5
PLD	—	0	1	1
OLD	—	2	1	3
Stimuli	umèle	umelle	unèle	unelle
No. of letters	5	4	5	4
PLD	—	0	1	1
OLD	—	2	1	2
Stimuli	triscat	triska	tricsat	triksa
No. of letters	7	6	7	6
PLD	—	0	1	1
OLD	—	2	1	3
Stimuli	blasc	blasque	plasc	plasque
No. of letters	5	7	5	7
PLD	—	0	1	1
OLD	—	3	1	4
Stimuli	neicle	nècle	niecle	nerle
No. of letters	6	5	6	5
PLD	—	0	1	1
OLD	—	2	1	2
Stimuli	kouvice	couvisse	xouvice	houvisse
No. of letters	7	8	7	8
PLD	—	0	2	1
OLD	—	3	1	3
Stimuli	karmol	carmole	kamrol	camrole
No. of letters	6	7	6	7
PLD	—	0	2	2
OLD	—	2	1	3

Note. PLD = phonological Levenshtein distance; OLD = orthographic Levenshtein distance.