

Reading and Reading-Related Skills in Children Using Cochlear Implants: Prospects for the Influence of Cued Speech

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We assessed the reading and reading-related skills (phonemic awareness and phonological short-term memory) of deaf children fitted with cochlear implants (CI), either exposed to cued speech early (before 2 years old) (CS+) or never (CS-). Their performance was compared to that of 2 hearing control groups, 1 matched for reading level (RL), and 1 matched for chronological age (CA). Phonemic awareness and phonological short-term memory were assessed respectively through a phonemic similarity judgment task and through a word span task measuring phonological similarity effects. To assess the use of sublexical and lexical reading procedures, children read pseudowords and irregular words aloud. Results showed that cued speech improved performance on both the phonemic awareness and the reading tasks but not on the phonological short-term memory task. In phonemic awareness and reading, CS+ children obtained accuracy and rapidity scores similar to CA controls, whereas CS- children obtained lower scores than hearing controls. Nevertheless, in phonological short-term memory task, the phonological similarity effect of both CI groups was similar. Overall, these results support the use of cued speech to improve phonemic awareness and reading skills in CI children.

Some studies have shown that deaf children using cochlear implants (CI) performed better on speech recognition tasks when both auditory and visual information (lipreading) were available compared to conditions in which only auditory information was available (Colin et al., 2008; Lachs, Pisoni, & Kirk, 2001; Leybaert & Colin, 2007; Rouger et al., 2007). Indeed, the addition of visual cues to auditory information allows deaf CI chil-

dren to acquire more accurate phonemic representations (Descourtieux, Groh, Rusterholtz, Simoulin, & Busquet, 1999; Medina & Serniclaes, 2009; Moreno-Torres & Torres, 2008). The implications of these results are two-fold. On the one hand, given their limited auditory experience, CI individuals naturally tend to rely more on lipreading than hearing people (Leybaert, Colin, & Hage, 2010; Rouger et al., 2007). On the other hand, the addition of lipreading alone to auditory information does not suffice to support speech development because previous studies suggest that the perception of speech sounds in CI children is less accurate than in hearing children (Geers, Brenner, & Davidson, 2003; Medina & Serniclaes, 2009; Tye-Murray, Spencer, & Gilbert-Bedia, 1995). Lipreading information is ambiguous: Cued speech is designed to eliminate this ambiguity (Cornett, 1967). Cued speech, which corresponds to cues accompanying mouth shapes, provides visual information that is much more precise than lipreading alone. When associated to the CI device, cued speech is expected to provide unambiguous access to phonological units. CI children exposed to cued speech are expected to develop more accurate phonemic representations than CI children who have never been exposed to cued speech by taking advantage of the interaction between visual and auditory information during development.

Accurate phonemic representations are needed to identify phonemes and to discriminate which phoneme among those in the inventory of a particular language a given stimulus represents. Research with

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hearing children has emphasized the importance of the accuracy of phonemic representations in the success of reading acquisition (in dyslexic children, Bogliotti, Serniclaes, Messaoud-Galusi, & Sprenger-Charolles, 2008, like in normally developing readers, Bradley & Bryant, 1983; Burnham, 2003; Hoonhorst et al., 2011; Lundberg, Olofson, & Wall, 1980). The successful acquisition of reading depends on the acquisition of related skills (phonemic awareness and phonological short-term memory), which in turn depends on the accuracy of phonemic representations. Many studies have provided evidence that the ability to identify and explicitly manipulate segments of speech, known as phonemic awareness, is fundamental in learning to read in an alphabetic system. This ability is required to grasp the principle of the alphabet, which must be understood before starting to decode written words. A child's degree of phonemic awareness has been proven in several longitudinal studies to be a good predictor of future achievement in reading (Fluss et al., 2009; Frost, Madsbjerg, Niedersoe, Olofsson, & Sorensen, 2005; Hulme, Goetz, Gooch, Adams, & Snowling, 2007; Lundberg et al., 1980; Savage & Carless, 2005; Stanovich, Cunningham, & Cramer, 1984). Experimental training studies have also evidenced a causal connection between phonemic awareness and reading (Ehri et al., 2001; Hulme et al., 2002). In addition, the ability to retain and manipulate phonological forms in short-term memory (phonological short-term memory) has been shown to contribute to reading achievement (Baddeley, 2003; Snowling, 2001). More specifically, during decoding, this ability makes it possible to retain the assembled phonological code derived from the use of grapheme-phoneme correspondences. Thus, the research literature amply supports the idea that for children to develop both reading-related skills and reading skills, they must have acquired accurate phonemic representations.

Influence of Cued Speech on Language Acquisition in Children Using CIs

Cued speech may facilitate the speech development of CI children. Numerous studies have experimentally demonstrated that cued speech contributes to the establishment of word representations in deaf people (with or without a hearing aid). In particular, many studies have

experimentally demonstrated that cued speech helps the deaf to establish auditory word representations in French (Alegria, Charlier, & Mattys, 1999; Charlier & Leybaert, 2000; Hage, Alegria, & Perier, 1990; LaSasso, Crain, & Leybaert, 2003; Leybaert & Charlier, 1996; Leybaert & LaSasso, 2010; Perier, Charlier, Hage, & Alegria, 1988) and in English (Duchnowski et al., 2010; Koo, Crain, LaSasso, & Eden, 2008; LaSasso & Crain, 2010; LaSasso & Metzger, 1998; Nicholls & Ling, 1982; Uchanski et al., 1994). These data imply that visual cues (mouth shapes and manual cues) are perceptually integrated and are able to facilitate the discrimination, identification, and manipulation of phonological units.

Although nowadays the majority of profoundly deaf children are fitted with CI, few studies provide any evidence about the impact of cued speech on speech perception in CI children. Two case studies describing the early development of language in a CI child have indicated that in each case, speech acquisition was influenced by exposition to cued speech (in French, Descourtieux et al., 1999; in Spanish, Moreno-Torres & Torres, 2008). To determine the influence of cued speech on speech production, Vieu et al. (1998) compared performance on a picture naming task in three groups of four CI children. The first group was exposed to speech only (average age of implantation: 7.7 years), the second group was exposed to Langue des Signes Française (LSF, a French version of the American Sign Language, average age of implantation: 7.1 years), and the last group was exposed to cued speech (average age of implantation: 6.5 years). After 36 months of implant use, the children whose scores improved the most were those who had been exposed to cued speech (44.3%), whereas the naming scores of CI children exposed to speech only or to LSF increased by 36.6% and 28.7%, respectively. We thus have an indication that cued speech seems to improve spoken language acquisition in CI children.

Reading-Related Skills in Children With CI

To our knowledge, no study has investigated the influence of cued speech on phonemic awareness and phonological short-term memory in CI children. Given the observed impact of cued speech on speech perception and production (Descourtieux et al., 1999; Moreno-Torres & Torres, 2008; Vieu et al., 1998), it is

quite possible that cued speech might help the development of these particular reading-related skills.

Previous studies on phonemic awareness have indicated that CI children are able to develop phonemic awareness, but the level they ultimately attain has yet to be determined. CI children fitted late (i.e., on average at 6 years) obtained scores significantly lower than hearing children matched for reading level (RL) or chronological age (CA) in a phonemic similarity judgment task (James, Rajput, Brinton, & Goswami, 2008). In contrast, CI children fitted early (i.e., on average at 2 years 10 months) performed in a similar way as hearing children matched for RL (mean CA: 6.8 years) and for CA (mean CA: 7.8 years) for items that are phonologically and orthographically congruent (James et al., 2008). Indeed, although CI children obtained lower scores than both RL and CA controls, *z*-scores were within the performance levels of the standard population. Spencer and Tomblin (2009) reported that CI children performed as accurately on a first-phoneme deletion task as hearing children matched for reading comprehension level. Thus, data on the development of phonemic awareness showed that CI children's performance can be interpreted as normal.

To our knowledge, only three studies have assessed phonological short-term memory in CI children, two of them with a pseudoword repetition task. First, Dillon, Burkholder, Cleary, and Pisoni (2004) showed that a sample of 76 children who had been fitted with CI at ages ranging from 1.9 to 5.4 years, and whose average CA at the time of testing was 8.9 years, only managed to repeat 42% of presented pseudowords correctly. Spencer and Tomblin (2009) found that CI children ranging in age from 7 years 2 months to 17 years 8 months (mean age at implantation: 3 years 7 months) obtained significantly lower scores on a pseudoword repetition task than hearing children matched for reading comprehension and ranging in age from 6 years 2 months to 17 years 9 months. Finally, the third study used a word span task and explored the effect of phonological similarity (Willems & Leybaert, 2009). Sequences of phonologically dissimilar words (e.g., ball, soon, life) are better recalled than sequences of words presenting phonological similarities (e.g., pet, bet, set). This phonological similarity effect is regularly observed (Baddeley, 1986; Fournet, Juphard,

Monnier, & Roulin, 2003; Nairne & Kelley, 1999; Watkins, Watkins, & Crowder, 1974) in word recall tasks. This effect suggests that words are encoded on the basis of the phonological information they contained. Willems & Leybaert (2009) showed that CI children (with a mean age at fitting of 37.6 months, and a mean CA of 6.9 years) presented a shorter span and reduced effect of phonological similarity compared to hearing children matched for CA, but a similar phonological similarity effect when compared to hearing children matched for span length. These results point to normally functioning phonological short-term memory in CI children. Their lower span seems due to heavier cognitive costs for word identification, which would leave less cognitive resources for memorization.

Development of Reading Skills in Children Using CI

Most studies on reading acquisition are based on the dual-route model (Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001; for a recent review, see Perry, Ziegler, & Zorzi, 2010), which holds that written words can be read either by a lexical or a sublexical procedure. The lexical procedure is said to give direct access to the orthographic word form from the participant's internal lexicon, whereas the sublexical procedure (in alphabetic scripts) consists of translating sublexical written units (graphemes) into sublexical units of the spoken language (phonemes), which are then assembled. This procedure might act as a bootstrapping mechanism upon which the lexical procedure can develop (Share, 1999). These two procedures are assumed to be used in parallel to process printed material, with processing tradeoffs that depend on the overall level of word identification (e.g., for English-speaking children: Backman, Bruck, Hebert, & Seidenberg, 1984; Waters, Seidenberg, & Bruck, 1984; for French-speaking children: Sprenger-Charolles, Siegel, Béchennec, & Serniclaes, 2003; Sprenger-Charolles, Siegel, & Bonnet, 1998). The efficiency of the lexical and sublexical procedures is usually assessed via the naming of irregular words and pseudowords, respectively, and the lexicality effect (faster and more accurate reading of words than pseudowords) is taken to indicate reliance on the lexical procedure for reading words and the sublexical procedure for pseudowords.

To determine whether reading skills in CI children show a deviant or delayed developmental trajectory, performance must be compared to that of hearing children matched for RL and CA. Skills are considered deficient and causally related to reading impairment when performance is lower than reading-level controls but only delayed as a consequence of the reading disability when performance is similar to reading-level controls (Bryant & Impey, 1986).

Again, very few published studies have assessed reading development in CI children according to their experience with cued speech. Torres, Rodriguez, Garcia-Orza, and Calleja (2008) indicated that the reading comprehension level of CI children (fitted at an average of 4.2 years old; average age of 12.6 years old at the time of the study) is similar to that of hearing children matched for RL or CA. Children tested were exposed intensively to cued speech, at home and with a speech therapist, starting at an average age of 12 months. The results of Medina & Serniclaes (2009) showed that the RL of children implanted from 2 to 3 years and aged from 6 to 11 years was similar to that of hearing children matched for CA. In this study, children were also exposed to cued speech, suggesting that the joint contribution of cued speech and CI enables reading acquisition with the same developmental time course as hearing children. Leybaert, Bravard, Sudre, and Cochard (2009) showed that reading scores for regular and irregular words were better for CI children exposed to cued speech (with a speech therapist and/or at home) than for CI children who had not been exposed to cued speech. However, both CI groups obtained lower accuracy scores than hearing children matched for grade level. These data strongly suggest that the use of cued speech with CI effectively aids deaf children in reading acquisition. However, neither Medina and Serniclaes (2009) nor Torres et al. (2008) directly compared CI children either exposed to cued speech or not. And in Leybaert et al. (2009), CI children were compared to hearing children of the same grade levels, which is roughly equivalent to a comparison with RL controls although there might be substantial differences in the reading performances between children of the same grade. Because our aim is to characterize the extent to which processing impairments are involved in reading acqui-

sition, it is highly relevant to compare CI children exposed to cued speech, CI children not exposed to cued speech, hearing children matched for RL, and hearing children matched for CA.

The Current Study

Studies on cued speech show very encouraging signs of joint contributions from cued speech and CI to reading acquisition, but methodological issues remain. It is necessary to combine comparisons between CI children who have been exposed to cued speech and those who have not, on one hand, with comparisons to the two types of hearing control (matched for either RL or CA), on the other. The aim of this article was to assess the reading-related skills (phonemic awareness and phonological short-term memory) and reading skills of French CI children exposed to cued speech. We sought to determine whether cued speech could influence the acquisition of reading and reading-related skills by comparing CI children exposed to cued speech (CS+) early (before age 2) and intensively (at home and with a speech therapist) and CI children who have never been exposed to cued speech (CS-). Because cued speech may speed the development of phonemic representations, it may also influence the development of reading-related skills and reading abilities. We thus evaluated whether the reading skills and reading-related skills of both CI groups developed normally or in an impaired fashion in comparison to those of hearing children matched for RL and CA. If cued speech positively influences reading acquisition, we expect that CS+ children will exhibit a level of reading and reading-related skills comparable to that of hearing children, whereas CS- children would present impairment or delay.

Methods

Participants

Eighteen children with CI (8 boys and 10 girls) were recruited from nine French school support services for the deaf located in different regions of France. All the children were congenitally deaf, had used a CI device for at least 5 years, and had been fitted with an implant before the age of 3 years 6 months. Different implants were used: 1 Clarion (Advanced Bionics), 16 Nucleus

24 devices (Cochlear Corporation), and 1 Digisonic (Neurelec). Children recruited ranged from 7 years 11 months to 11 years, and from grades 2–4. Their age at implantation ranged from 1 year 10 months to 3 years 6 months. Only one child had deaf parents. Table 1 describes the characteristics of the two CI groups (CS+ and CS–). Before implantation, all children used conventional hearing aids and were still using them—even if only occasionally—in their nonimplanted ear. Before and after implantation, 9 out of 18 CI children used cued speech early (before the age of 2) and with intensive practice (at home and with speech therapist). These children composed the CS+ group. To be selected for the CS+ group, they had to obtain more than 80% of correct responses to the TERMO test (Descourtieux & Busquet, 2003) in which children have to name the words presented with visual signals (keys and lipreading) but without an auditory signal. Nine other CI children composed the CS– group. Among them, six children used spoken language, that is they exclusively used speech and audition to communicate, two had been exposed to both spoken language and LSF, and one child was exposed to both spoken language and signed French (Français signé¹). The children in the CS– group had never been exposed to cued speech. Thirteen out of the 18 CI children were enrolled in mainstream classes with hearing children. The remaining five children were in a spoken language classroom in a special school (special education with spoken language instruction).

To compare the performance of the CI groups and the two hearing groups, each child with CI was matched with one hearing child with the same RL and with one hearing child with the same CA. All the

hearing children met the following criteria: (a) they were native speakers of French and (b) they had no history of auditory, language, or reading disorders. The RL was obtained using the Alouette test (Lefavrais, 1967), a standardized French reading test used in assessment for developmental dyslexia (i.e., Bogliotti et al., 2008; Casalis, Colé, & Sopo, 2004; Sprenger-Charolles, Colé, Kipffer-Piquard, Pinton, & Billard, 2009; Ziegler et al., 2008; Ziegler, Pech-Georgel, George, & Lorenzi, 2009). This test requires participants to read a meaningless text aloud; their performance is then converted into a reading age. The Alouette test was standardized for the reading performance of children ages 5–14 and a composite score (called “reading score”) that took both accuracy and speed into account was calculated. The families of all the participants (both CI children and hearing children) were informed about the goals of the study and provided written consent before their child’s participation.

As indicated in Table 2, the CAs of the CS+ and CS– groups are the same as those of CA group ($t < 1$, $t < 1$) but are significantly higher than those of the RL group— $t(16) = 4.02$, $p < .001$; $t(16) = 4.33$, $p < .001$, respectively. The reading scores of the CS+ and CS– groups are similar to those of the RL group ($t < 1$, $t < 1$) but significantly lower than those of the CA group— $t(16) = 3.82$, $p < .001$; $t(16) = 4.51$, $p < .001$, respectively. Moreover, the reading scores of CS+ children are significantly higher than those of CS– children— $t(16) = 3.30$, $p < .01$. The nonverbal reasoning scores of all groups, tested using the progressive matrices (PM47, Raven, 1947), were within the normal range. The PM47 scores of CS+ and CS– children did not differ significantly from those of the

Table 1 Characteristics of children with cochlear implant

CI groups	Chronological age (years; months) Mean (<i>standard deviation in parentheses</i>)	Age at implantation (years; months) Mean (<i>standard deviation in parentheses</i>)	Length of CI use (years; months) Mean (<i>standard deviation in parentheses</i>)	Communication mode	Educational placement
CS– ($N = 9$)	9;1 (0;8)	2;8 (0;5)	6;5 (1;1)	Six oral, two oral + LSF; one oral + signed French	Four special education, five mainstream
CS+ ($N = 9$)	8;8 (1;1)	2;6 (0;9)	6;2 (1)	Nine early and intensive cued speech + oral	Eight mainstream, one special education

Note. CI, cochlear implants; CA, chronological age; LSF, Langue des Signes Française.

Table 2 Means (*SD*) of CI and NH participants' CA, listening age, and nonverbal IQ level

	CA (years; months)	Reading age (Alouette test) (years; months)	PM47	
			/36	Percentiles
CS-	9;1 (0;8)	7;1 (0;4)	27 (6)	25th
CS+	8;8 (1;1)	7;9 (0;7)	28 (5)	25th
NH-RL	7;6 (0;6)	7;6 (0;9)	27 (4.5)	50th
NH-CA	9;1 (0;9)	9;1 (1)	34 (5)	75th

Note. CI, cochlear implants; CA, chronological age; NH-RL, normal-hearing children matched for reading level; and NH-CA, normal-hearing children matched for chronological age.

RL group— $t(16) = 1.21, p > .20$; $t(16) = 1.18, p > .20$, respectively—but were significantly lower than those of CA children— $t(16) = 2.82, p < .01$; $t(16) = 3.25, p < .01$, respectively.

Experimental Tasks

Two tasks were administered in order to assess the development of participants' reading-related skills development. The first was a phonemic similarity judgment task that assessed phonemic awareness. The second task was a word span task assessing phonological short-term memory.

A reading task was used to evaluate reading skills and possible between-group differences in the use of sublexical and lexical procedures. Because in the studies reported in the introduction only percentage of correct responses was used, leading to potential ceiling effects, we measured both accuracy and processing time, to take possible speed-accuracy trade-offs into account and to provide a fine-grained measure of performance (see e.g., Sprenger-Charolles et al., 2003).

Reading-related skills. For tasks assessing reading-related skills, words are very frequent (and assumed to be known by all the participants—frequent and familiar): one and a half per 100 words, corresponding to a standard frequency effect of 85 (MANULEX, Lété, Sprenger-Charolles, & Colé, 2004). In order to ensure that the children knew the words that were represented by the pictures, and use the appropriate names for the pictures, they had to name each picture during its presentation. We observed that no children made mistake in naming pictures.

Phonemic Awareness—Similarity Judgment Task

For each trial in the test, children were instructed to name three pictures (e.g., savon-bouton-balai; soap-

button-brush) and to indicate the two pictures that begin with the same sound. In each trial, the three items are matched for length (number of letters, phonemes, and syllables) as well as written frequency. The mean length of all the words was 5.2 letters (*SD* 0.9), 3.3 phonemes (*SD* 0.7), and 1.3 syllables (*SD* 0.5).

Procedure: The children were instructed to name the three pictures displayed in the center of the screen and to choose the two pictures whose names begin with the same sound as accurately and as quickly as possible. Practice items were used to familiarize the children with the material and to make sure that they understood the instructions. The procedure on each trial was as follows. A fixation cross remained in the center of the screen for 500 ms and was immediately followed by the three pictures. Children answered by pointing to the two pictures whose names begin by the same sound. The pictures remained on the screen until the participant had finished performing this similarity judgment, at which point the experimenter triggered the presentation of the next item. No feedback was given.

The order in which the items were administered was random across children, and each of the items was presented only one time. The positions of the three pictures displayed on a trial were also randomly distributed across children.

Phonological Short-Term Memory—Word Span Task

The second task, controlled by E-prime 2.0 and running on a Dell PC, was a word recall task where each word is represented by a picture. To assess phonological short-term memory, we measured a phonological similarity effect. We manipulated the phonological similarity of words, comparing the children's ability

to repeat a series of phonologically similar words (e.g., bateau-râteau-château; boat-rake-castle) or a control series of phonological dissimilar words (e.g., cochon-tapis-lapin; pig-carpet-rabbit). Within each list and between the lists, items were matched for length (number of letters, phonemes, and syllables) and written frequency. Their mean length was 5.3 letters (*SD* 1), 3.5 phonemes (*SD* 0.6), and 1.5 syllables (*SD* 0.5) for phonologically similar words and 5.5 letters (*SD* 1.2), 3.6 phonemes (*SD* 0.4), and 1.6 syllables (*SD* 0.5) for phonologically dissimilar words (all $t < 1$). Series contained two to five pictures (eight blocks per number of pictures in a series: eight blocks of two, eight blocks of three, etc.). A total of thirty-two blocks comprised of between two and five pictures were presented. Children were presented with the eight blocks containing two pictures; if they achieved at least 50% correct responses, the following block (containing three pictures) was presented, and so on. The accuracy of ordinate recall was measured through span, percentage of correct responses, and latency time. These scores were measured in counting recall errors that were due to order errors and not to errors of item naming. Indeed, during the recall, children had to point pictures and not to name it. No feedback was given during test. Practice items were used to familiarize children with the material and to make sure that they understood the instructions.

Procedure: A fixation cross remained in the center of the screen for 500 ms and was immediately followed by pictures that were presented one by one in a block. Each picture remained in the center of the screen for 2500 ms. Children had to name each picture during its presentation. At the end of each block, the pictures were presented simultaneously, and the child had to indicate the order in which the pictures had been presented. Pictures remained on the screen until the participant had finished recalling the order of presentation, at which point the experimenter triggered the presentation of the next item. The order in which the lists were administered was randomized across children, and all the items in each block were presented only one time in a random order. The positions of the pictures on the screen in the recall step were randomly distributed for each child.

Reading task. To assess the acquisition of the different reading procedures, we used pseudowords, assumed to be the best “signature” of the sublexical procedure in grades 1–4, and irregular words, considered as the best indicator of the use of the lexical procedure with CI children in grades 2–5 (Sprenger-Charolles, Colé, Béchenec, & Kipffer-Piquard, 2005).

Both lists were composed of 30 irregular words (e.g., orchestre, pied) and 30 pseudowords (e.g., supon, pitode). Within each list and between lists, the items were matched for length (number of letters, phonemes, and syllables) and orthographic frequency (frequency of bigrams, Content and Radeau, 1988). Mean length was 5.7 letters (*SD* 1.7), 4.1 phonemes (*SD* 1.6), and 1.6 syllables (*SD* 0.6) for irregular words and 5.6 letters (*SD* 1.6), 4.4 phonemes (*SD* 1.8), and 1.7 syllables (*SD* 0.5) for pseudowords (all $t < 1$). Their mean orthographic frequency was 36 (*SD* 11.6) and 37 (*SD* 13.3) respectively for irregular words and pseudowords ($t < 1$). In order to ensure comparable measurements for latency, the items in each list were also matched for their initial grapheme.

Procedure: The children were instructed to read the item displayed in the center of the screen aloud as accurately and as quickly as possible. Practice items were used to familiarize children with the material and to make sure that they understood the instructions. No feedback was given. The procedure on each trial was as follows. A fixation cross remained in the center of the screen for 500 ms and was immediately followed by the test item. The item remained on the screen until the participant had finished reading aloud, at which point the experimenter triggered the presentation of the next item.

Response latency and accuracy were recorded. A sound card was used to record the children’s vocal responses in individual files. The software calculated latency as the interval between the stimulus onset on the screen and the detection of the onset of the spoken response. The software allowed for manual readjustment if necessary and the elimination of latencies on incorrect responses. This enabled the experimenter to ensure that no invalid latencies were included and to calculate the percentage of correct responses. The order in which the two lists were administered was random across children, and all the items were presented only one time in a random order.

CI and hearing children were tested individually in a quiet room (at home and at school, respectively). They performed all tasks (Alouette test, PM47, phonemic awareness, phonological short-term memory, and reading tasks) during a single session that lasted around 30 min.

Results

Phonemic Awareness Task

The percentage of correct responses and latencies were entered in two repeated-measures analyses of variance (ANOVAs) using either participants ($F1$) or items ($F2$) as factors. In the $F1$ ANOVAs running on phonemic awareness scores, Group (CS+ vs. CS- vs. hearing group matched for RL vs. hearing group matched for CA) was a between-participant factor. The design of both $F2$ ANOVAs had Group as a within-items factor. Differences in the accuracy and rapidity of responses between groups were tested for a Group effect using planned comparisons² between groups. The average scores of CS+, CS-, and hearing control groups on the phonemic awareness task are presented in Table 3.

For accuracy measures, significant effect of Group was found— $F1(3,50) = 3.22, p < .05; F2(3,42) = 20.3, p < .001$. The group effect was due to greater phonemic awareness scores for CA, RL, and CS+ children compared to CS- children—respectively, $t1(50) = 2.21, p < .05; t2(14) = 4.93, p < .001; t1(50) = 2.75, p = .01, t2(14) = 3.50, p < .01; t1(50) = 2.84, p < .001, t2(14) = 5.91, p < .001$. CA, RL, and CS+ children obtained similar scores (comparison of CA and RL: $t1 < 1, t2 < 1$; comparison of CA and CS+: $t1(50) = 1.11, p > .20, t2 < 1$; comparison of RL and CS+: $t1 < 1, t2 < 1$).

For latency time measures, analyses were conducted on correct answers only. Errors were removed from analyses. We found significant effect of Group— $F1(3,48) = 3.52, p < .05; F2(3,42) = 18.2, p < .001$. The group

effect was due to shorter latencies for CA, RL, and CS+ children compared to CS- children—respectively, $t1(48) = 2.52, p < .05, t2(14) = 5.31, p < .001; t1(48) = 3.73, p < .01, t2(14) = 4.35, p < .001; t1(48) = 3.82, p < .001, t2(14) = 5.71, p < .001$. CA, RL, and CS+ children all obtained similar latencies (for all comparisons: $t1 < 1, t2 < 1$).

Phonological Short-Term Memory

Percentage of correct responses and latency times were entered into two repeated-measures ANOVAs using participants ($F1$) as a factor. The $F1$ ANOVA involved Similarity (phonologically similar words vs. phonologically dissimilar words) as a within-participants factor and Group (CS+ vs. CS- vs. RL vs. CA) as a between-participants factor. Differences in scores of word recall between groups were tested for a main effect, and planned comparisons between groups were also performed. The similarity effect is the difference in precision (percentage of correct responses) and in rapidity of word recall between phonologically similar words and phonologically dissimilar words. Differences in the Similarity effect between groups were tested with the Similarity \times Group interaction and with planned comparisons for each group. For latency time measures, analyses were conducted on correct answers only.

Average scores of percentage of correct responses and latency times of CS+, CS-, and hearing control groups on the phonological short-term memory task are presented in Table 4.

For accuracy measure, a significant main effect was found for Group— $F1(3,50) = 14, p < .001$ —and for Similarity— $F1(1,50) = 12, p = .001$. The group effect was due to greater scores for CA children, compared to CS+ and CS- children—respectively, $t1(50) = 4.47, p < .001; t1(50) = 5.74, p < .001$ —and for RL children compared to CS+ and CS- children—respectively,

Table 3 Percentage of correct responses and latencies (SD) for the phonemic similarity judgment task

CS-	Percentage of correct responses			CS-	Latency times (in seconds)		
	CS+	NH-RL	NH-CA		CS+	NH-RL	NH-CA
79.3 (25)	99.3 (22)	92.2 (17)	93.1 (15)	6.15 (2.8)	4.54 (1.2)	4.63 (1.5)	3.63 (1.3)

Note. NH-RL, normal-hearing children matched for reading level and NH-CA, normal-hearing children matched for chronological age.

Table 4 Scores of percentage of correct responses and latency times (*SD*) for recall task for phonologically similar words and phonologically dissimilar words

	Percentage of correct responses			
	CS-	CS+	NH-RL	NH-CA
Phonologically similar items	57.7 (15.3)	62.4 (8.4)	64.2 (8.7)	70.1 (8.9)
Phonologically dissimilar items	55.9 (16.2)	60.5 (15.9)	76.4 (10.9)	83.6 (6.5)
	Latency times (in seconds)			
	CS-	CS+	NH-RL	NH-CA
Phonologically similar items	8.5 (2.4)	6.9 (1.5)	8.9 (1.8)	7.1 (1.7)
Phonologically dissimilar items	6 (2.3)	5.1 (1.1)	7.1 (1.6)	5.1 (1.5)

Note. NH-RL, normal-hearing children matched for reading level and NH-CA, normal-hearing children matched for chronological age.

$t(50) = 2.71, p < .05$; $t(50) = 3.99, p < .01$. Whereas CS+ and CS- children obtained similar scores, $t(50) < 1$, CA children obtained greater scores than RL children, $t(50) = 2.76, p < .05$. The Group \times Similarity interaction was significant— $F(3,50) = 7.34, p < .001$. CA and RL groups presented a Similarity effect—respectively, $t(50) = 4.78, p < .001$; $t(50) = 5.23, p < .001$ —whereas CS+ and CS- groups did not—for both groups, $t(50) < 1$.

For latency, a significant main effect was found for Group— $F(3,50) = 13.42, p < .001$ —and for Similarity— $F(1,50) = 27.12, p < .001$. The group effect was due to shorter latencies for CA children compared to RL and CS- children—respectively, $t(50) = 5.31, p < .001$; $t(50) = 2.55, p < .05$ —and to shorter latencies for CS+ children compared to RL and CS- children—respectively, $t(50) = 5.01, p < .001$; $t(50) = 3.01, p < .05$. Results also showed that CA and CS+ children obtained similar latencies ($t < 1$) and that RL and CS- children performed similarly ($t < 1$). The Group \times Similarity interaction was not significant ($F < 1$). CA, RL, CS+, and CS- groups presented a Similarity effect—respectively, $t(50) = 4.62, p < .001$; $t(50) = 2.09, p < .05$; $t(50) = 2.02, p < .05$; $t(50) = 3.28, p < .01$.

Reading skills. Percentage of correct responses and latencies were entered into two repeated-measure ANOVAs performed using either participants ($F1$) or items ($F2$) as factors. $F1$ ANOVAs run on irregular word and pseudoword reading scores involved Lexicality (irregular words vs. pseudowords) as a within-participants factors and Group (CS+ vs. CS- vs. RL vs. CA) as a between-participants factor. The design of both $F2$ ANOVAs involved Lexicality as a between-

items factor and Group as a within-items factor. Differences between groups in the precision and rapidity of reading were tested with the Group effect and with planned comparisons between groups. A lexicality effect corresponds to a difference in accuracy and rapidity of reading between pseudowords and irregular words. Differences between groups in the presence and extent of lexicality effects were tested with the Lexicality \times Group interaction and with planned comparisons for each group.

Response Accuracy

Figure 1 presents the mean reading scores for irregular words and pseudowords (expressed in percentage of correct responses) for each group. Among main effects, a significant effect was found for Group— $F(3,50) = 8.44, p < .001$; $F(2,174) = 32.9, p < .001$. The group effect was due to the greater reading scores of CA, RL, and CS+ children compared to CS- children for both irregular words and pseudowords—respectively, $t(50) = 5.54, p < .001$, $t(58) = 10.4, p < .001$; $t(50) = 2.44, p < .05$, $t(58) = 9.84, p < .001$, $t(50) = 3.38, p < .01$, $t(58) = 11.5, p < .001$. Additionally, whereas RL children scored lower than to CA children— $t(50) = 3.36, p < .01$, $t(58) = 8.64, p < .001$ —the scores of CS+ children were similar to those of both RL and CA children— $t(50) = 1.23, p > .20$, $t(58) < 1$; $t(50) = 1.42, p = .15$, $t(58) < 1$, respectively.

The effect of lexicality was also found to be significant— $F(1,50) = 65.6, p < .001$, $F(2,158) = 15.2, p < .001$ —specifically, pseudowords were read with more accuracy than irregular words.

The Group \times Lexicality interaction was also significant— $F(3,50) = 4.52, p < .01$, $F(2,174) =$

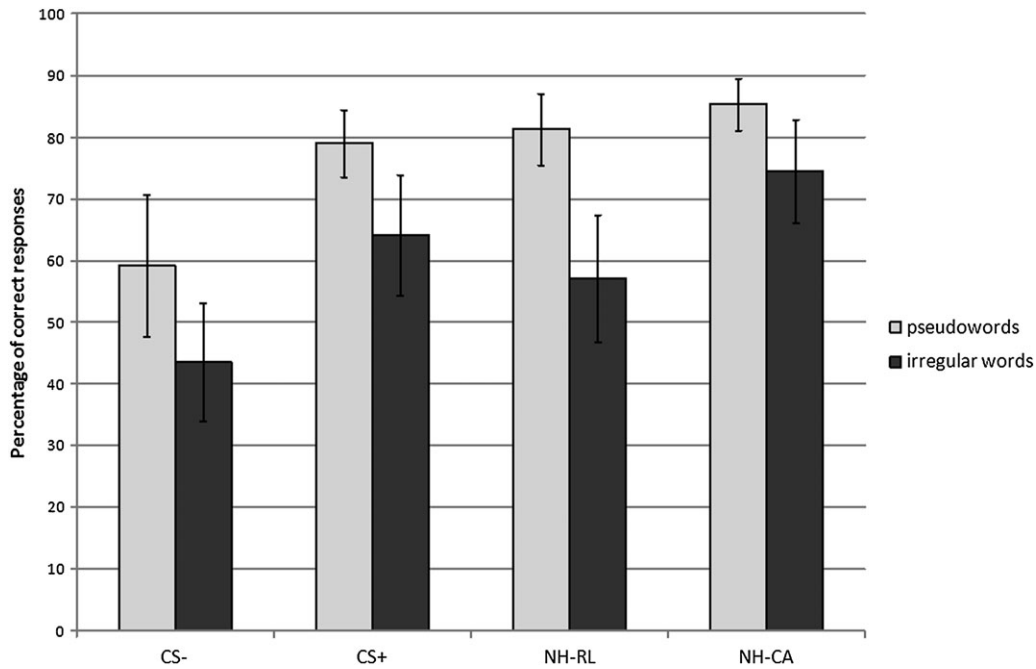


Figure 1 Percentage of correct responses on a reading aloud task for irregular words and pseudowords for hearing children matched for chronological age (CA), hearing children matched for reading level (RL), children using cochlear implant and exposed to cued speech (CS+), and children using cochlear implant and never exposed to cued speech (CS-).

12.3, $p < .001$. Although each group presented a lexicality effect— $t1(50) = 3.07$, $p < .01$; $t2(58) = 2.60$, $p < .05$, for CS- children, $t1(50) = 2.90$, $p < .01$; $t2(58) = 2.44$, $p < .05$, for CS+ children, $t1(50) = 3.54$, $p < .001$; $t2(58) = 2.42$, $p < .05$, for CA children, $t1(50) = 7.93$, $p < .001$; $t2(58) = 4.78$, $p < .001$, for RL children—the difference in favor of pseudowords was larger for RL children than for CA, CS+, and CS- children—respectively, $t1(50) = 3.62$, $p < .001$, $t2(58) = 7.33$, $p < .001$; $t1(50) = 2.23$, $p < .05$, $t2(58) = 3.54$, $p < .01$; $t1(50) = 2.25$, $p < .05$, $t2(58) = 3.22$, $p < .01$. Among the latter three groups (CA, CS+, and CS- children), the lexicality effect was similar (all comparisons: $t1 < 1$, $t2 < 1$). The difference between the mean percentage correct responses for pseudowords minus irregular words for RL, CA, CS+, and CS- children was 24%, 11%, 16%, and 15%, respectively.

Latency

Figure 2 presents the mean reading latencies for irregular words and pseudowords (expressed in milliseconds) for each group. Among main effects, a significant effect was found for Group— $F1(3,44) = 6.34$, $p < .001$,

$F2(3,174) = 7.54$, $p < .001$. The group effect indicates that CS- children read pseudowords and irregular words less rapidly than CS+, RL, and CA children—respectively, $t1(44) = 3.54$, $p < .001$, $t2(58) = 4.21$, $p < .001$; $t1(44) = 3.11$, $p < .01$, $t2(58) = 4.42$, $p < .001$; $t1(44) = 4.14$, $p < .001$, $t2(58) = 5.85$, $p < .001$. RL, CA, and CS+ children showed similar latencies (for all comparisons, $t1 < 1$, $t2 < 1$). A significant effect was also found for Lexicality— $F1(1,44) = 16.5$, $p < .001$, $F2(1,58) = 11.2$, $p < .01$ —with irregular words read more rapidly than pseudowords. The Group \times Lexicality interaction was not significant— $F1(3,44) = 1.70$, $p > .15$, $F2 < 1$. The lexicality effect was significant for each group— $t1(44) = 2.45$, $p < .05$; $t2(58) = 3.32$, $p < .05$, for CS- children, $t1(44) = 2.34$, $p < .05$; $t2(58) = 3.46$, $p < .05$, for CS+ children, $t1(44) = 2.70$, $p < .05$; $t2(58) = 3.16$, $p < .05$, for CA children, $t1(44) = 2.61$, $p < .05$, $t2(58) = 3.23$, $p < .05$, for RL children.

Discussion

This article was designed to investigate the reading and reading-related skills of French CI children, either exposed to cued speech or not (CS+ vs. CS-) in

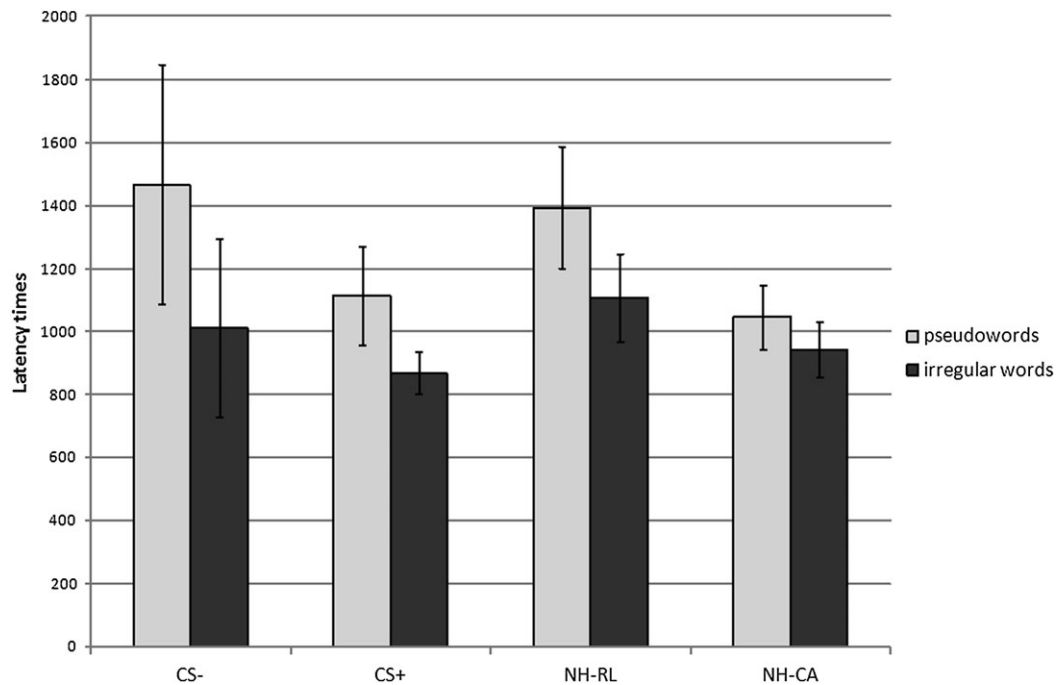


Figure 2 Latency times on a naming task for irregular words and pseudowords reading for hearing children matched for chronological age (CA), hearing children matched for reading level (RL), children using cochlear implant and exposed to cued speech (CS+), and children using cochlear implant and never exposed to cued speech (CS-).

comparison with hearing control children matched for RL and CA. Because previous evidence suggested that cued speech influences speech and reading development in deaf children using hearing aid (Charlier & Leybaert, 2000; Leybaert, 2000; Leybaert & Charlier, 1996; Leybaert & Lechat, 2001), direct study of the influence of cued speech on CI's children reading and reading-related skills seemed valuable. We thus explored the links between the quality of phonemic representations and the development of phonemic awareness, phonological short-term memory, and reading skills.

We found that exposure to cued speech influences phonemic awareness. CS+ group presented accuracy and latencies similar to both hearing control groups, whereas CS- obtained lower scores than CS+ and hearing children. Nevertheless, regardless of exposure to cued speech, CI children seem use similarly the phonological representations of words in order to complete a word span task. In phonological short-term memory, cued speech might not influence the quality and the rapidity of the use of phonological representations.

The reading task showed that cued speech influences the ability to read. CS+ children read items (pseudowords and irregular words) with accuracy and rapidity similar to that of both hearing control groups whereas CS- children read pseudowords and irregular words with lesser accuracy and rapidity than hearing controls. Cued speech might influence only the quality of the use of reading procedures, but not the processing involved in reading. A lexicality effect was observed in both accuracy and latency time scores for all groups and was similar for CA, CS+, and CS-, indicating that all groups read pseudowords through the sublexical procedure and irregular words through the lexical procedure.

In summary, our study showed that children exposed early to cued speech are better at phonological processing than CI children never exposed to cued speech. CI children exposed to cued speech develop better abilities at manipulating and identifying phonemes, that is phonemic awareness, and better correspondences between grapheme and phoneme for reading. However, we found no impact of cued speech on processing implied in phonological short-term memory.

The Influence of Cued Speech on Reading-Related Skills in Children Using CI

The comparisons of the CI children with both RL-matched and CA-matched groups aimed to determine whether the phonological skills that are related to reading success develop normally in CI children (performance similar to CA children), and if not, whether the observed phonological impairments constitute a deficit (lesser performance than RL group) or a delay (performance similar to RL children). As expected, CS+ children obtained scores similar to those of both hearing groups, whereas CS- children were outperformed by hearing controls on the phonemic awareness task. Impairment in both accuracy and latency were observed for the phonemic similarity judgment task, indicating a deficit in phonemic awareness in CS- children. These results are congruent with those of Descourtieux et al. (1999), Moreno-Torres and Torres (2008), and Vieu et al., (1998) that showed that cued speech improves the speech perception and production abilities of CI children. By improving the quality of phonemic representations, cued speech enhances the ability of CI children to identify and manipulate phonemes.

Results on a short-term memory task present a different pattern because CI children in both the CS+ and CS- groups were outperformed by CA and RL children on the accuracy scores. Moreover, as expected with both hearing groups, CS+ and CS- children presented a phonological similarity effect because they recalled phonologically dissimilar words more rapidly than phonologically similar ones. The results observed in the short-term memory task might be explained by the absence of influence of cued speech in processing strategies used by CI children. Nevertheless, cued speech might influence only the rapidity of processing implied in word span task because we observed that CS+ children recalled items as rapidly as CA children whereas CS- children recalled items as rapidly as RL children.

Our results suggest a relationship between cued speech and phonemic awareness and therefore confirm the results of previous research indicating that cued speech promotes the acquisition of phonemic representations in CI children. As suggested above,

these results showed that CI children exposed to cued speech develop better identification and manipulation of phonemes than CI children who have not been exposed to cued speech. Our results showed that CS+ children obtained scores similar to those of both hearing groups, whereas CS- children were outperformed by hearing controls on the phonemic awareness task. Thus, phonological representations of CS- children are less accurate than those of hearing children. Because we do not observe the same difficulty in CS+ children, we can think that this difficulty is not due to a lesser amount of experience with speech sounds as a result of deafness or late implantation. But when the task (word span task) implied the memorization of words, CI children performed on the basis of phonological representations and this regardless of exposure to cued speech. As a whole, cued speech seems to improve the phonemic processing involved in speech perception and allows children with CI to develop abilities similar to those of hearing children.

The Influence of Cued Speech on the Use of Lexical and Sublexical Procedures in CI Children

The major characteristics of CI children's performance on the reading task can be summarized as follows. Cued speech influences the development of both lexical and sublexical procedures. CS- children recognized irregular words and pseudowords with lesser accuracy than both hearing groups, whereas CS+ children obtained scores similar to those of both hearing groups. These results indicate a deficit in the use of lexical and sublexical procedures in CI children never exposed to cued speech. Nevertheless, we observed a lexicality effect in all four groups, suggesting that CI and hearing children used the sublexical procedure to recognize pseudowords and the lexical procedure to recognize irregular words.

These results reproduce those obtained in earlier studies with French-speaking children. In particular, Bouton, Serniclaes, and Colé (2011) showed a similar lexicality effect on response time in CI and hearing children matched for CA. Another study with English-speaking children also showed that CI children are able to use the sublexical procedure because they read words and pseudowords as accurately as

hearing children matched on grade level (Geers, 2003; Vermeulen, van Bon, Schreuder, Knoors, & Snik, 2007). The success of CI children in using the lexical procedure to read regular words was also reported by Geers (2003) and Fagan, Pisoni, Horn, and Dillon (2007), who showed that the majority of CI children obtained scores similar to those of hearing children at the same grade level and with the same CA, respectively.

In spite of some abilities similar to those of hearing children, CS– children recognized written items with less accuracy and rapidity than hearing groups. These results completed the findings of Leybaert et al. (2009) who showed that CS+ children obtained better accuracy scores in regular and irregular words reading than CS– children. Leybaert et al. also reported that CS+ children obtained lower scores than hearing children matched for grade level. Our findings showed that CS+ children obtained accuracy and latency scores similar to those of hearing children matched for RL and CA. Taken together, these results indicate that CS– children present difficulties in using both reading procedures: they make more errors in written item recognition and read items more slowly than hearing children. These difficulties could be explained by a lower quality of phonological representations.

Relationship Between Reading-Related Skills and Reading Procedures

Our basic aim with the three tasks presented here was to delineate more precisely the abilities of CI children, either exposed to cued speech or not, to identify, manipulate and memorize phonemes, and to use lexical and sublexical reading procedures. Considering the fact that the sublexical procedure is an important function in reading acquisition, particularly in alphabetic writing systems (for review, see Sprenger-Charolles, Colé, & Serniclaes, 2006), the lesser efficiency with which CI children use the sublexical procedure to read pseudowords is assumed to be due to less accurate phonemic representations. Unlike hearing children, who can rely on phonemic representations in the use of the sublexical procedure (Goswami, Ziegler, Dalton, & Schneider, 2001), CI children might rely on psycholinguistic units of various sizes, including orthographic representations of whole words.

The CS– children showed a deficit in phonemic awareness and in the use of sublexical and lexical procedures, but appeared to be able to use each of these procedures to read pseudowords and irregular words, respectively. Difficulties using sublexical and lexical procedures could be explained by a lesser use of phonemic representations in reading because CS+ children did not present these difficulties. CS+ children demonstrated phonemic awareness and reading skills similar to hearing children. Again, the pattern of results supports the view that cued speech improves the quality of phonemic representations (Colin et al., 2008; Leybaert & Charlier, 1996; Leybaert & Colin, 2007). Phonemic awareness and the use of sublexical and lexical procedures depend on the quality of phonemic representations and on the ability of children to manipulate or use them in reading. Our results suggest that phonemic units are more accurately used in reading by CS+, CA, and RL children than by CS– children. Obviously, CS– children were able to use the grapheme–phoneme sublexical strategy, but did so less accurately and rapidly than CS+ and hearing children. In addition, the sublexical reading procedure is seen as the bootstrapping mechanism on the basis of which the lexical (or orthographic) procedure can develop (Share, 1995, 1999; Sprenger-Charolles et al., 1998, 2003). The development of this procedure can thus have an impact on the development of the lexical procedure. Our results suggest that this might be also the case for CI children because CS– children read irregular words with less accuracy and longer latencies than hearing children.

In conclusion, cued speech appears to improve CI children's ability to identify and manipulate phonemic units, as well as their ability to use lexical and sublexical word reading procedures. Our results thus indicate that CI children draw advantages from being exposed to cued speech. Our conclusions need to be confirmed by future studies comparing the development of phonemic representations in CI children either exposed to cued speech or not. The finding that phonemic representations are more accurate in CS+ children would support the hypothesis that speech perception abilities mediate the relationship between phonological representations and reading skills. Thus, future research should directly compare the phonemic

perception abilities and reading skills of CI children based on their exposure to cued speech. Spelling tasks of irregular words and pseudowords might be used.

Notes

1 Signed French (français signé) corresponds to the use of LSF according to the linear syntax of spoken French.

2 For planned comparisons realized in three tasks, we used the Boole–Bonferroni correction in order to limit alpha error.

Conflicts of Interest

No conflicts of interest were reported.

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