Oxford Handbooks Online

The Role of Cued Speech in Language Development of Deaf Children

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The Oxford Handbook of Deaf Studies, Language, and Education, Volume 1, Second Edition (2 ed.)
Edited by Marc Marschark and Patricia Elizabeth Spencer

Print Publication Date: Jan 2011
Online Publication Date: Sep 2012
Subject: Psychology, School Psychology, Developmental Psychology
DOI: 10.1093/oxfordhb/9780199750986.013.0020

Abstract and Keywords

Cued Speech (CS) is a manual communication system that makes use of visual information from speechreading combined with handshapes positioned in different places around the face in order to deliver completely unambiguous information about the syllables and the phonemes of spoken language. This chapter reviews research showing that CS (i) enhances speech perception, (ii) facilitates language development in the phonological, lexical, and morpho-syntactical domains, and (iii) allows the development of robust and precise phonological representations, which are recruited in cognitive abilities such as rhyming, remembering, reading, and spelling. Findings from research reviewed also shows that early exposure to CS, before learning to read, facilitates the acquisition of the alphabetic principle. We also discuss two new research lines about CS: (1) How is CS processed by the brain and the similarities and differences with the processing of audio-only and audio-visual language and (2) Is CS compatible with a cochlear implant? We support our view that exposure to CS before or after implantation could be important in the aural rehabilitation process of cochlear implantees.

Keywords: Cued Speech, acquisition of phonology, morpho-syntactic development, lexical development, cochlear implant, cerebral lateralization, neuro-functional anatomy of language processing

Despite normal intelligence and normal potential for learning, children born profoundly deaf generally exhibit lags across all activities involving phonological representations based on speech: speech perception and speech production, oral language development, metaphonological abilities, immediate ordered memory for linguistic stimuli, reading, and spelling. In addition, their pattern of hemispheric specialization for language processing is generally atypical. The most likely explanation of these findings lies in deaf children's reduced access to oral language through lipreading.

It is now widely recognized that lip movements involved in the production of speech are automatically processed by hearing persons in normal conditions of listening. The fact that visual speech information influences the automatic processing of auditory information (McGurk & MacDonald, 1976) indicates that the visual speech information is dealt with by structures in the brain common to those involved in the processing of the auditory signal (Calvert et al., 1997). Hearing people thus develop phonological representations through access to lipreading as well as through acoustic information. The basis for the development of such amodal, perceptual representations of speech seems to occur during the first weeks of life (Burnham & Dodd, 1996; Kuhl & Meltzoff, 1982; MacKain, Studdert-Kennedy, Spieker, & Stern, 1983).

(p. 277) Lipreading constitutes the primary input for deaf children to gain information about the phonological structure of spoken language (Dodd, 1976). Although lipreading provides information about some phonological contrasts (e.g., place of articulation), it does not afford the perception of others, like nasality and voicing (Erber, 1974; Walden, Prosek, Montgomery, Scherr, & Jones, 1977). Through lipreading deaf children have access only to phonetically underspecified information, and they develop underspecified representations with respect to heard-and-spoken language. This hinders deaf children's acquisition of oral language and of all cognitive activities that rely upon phonological representations.

To help deaf children perceive information about the phonological structure of spoken language through the visual channel, different systems have been elaborated. One of these systems is Cued Speech (CS) (Cornett, 1967). Reviewing previous research on the effect of CS allows one to examine whether the development of a phonological system depends on the delivery of accurate information about phonological contrasts, independently of the modality. More specifically, if phonological representations can be elaborated on the basis of a well-specified visual input, then the development of all abilities relying on such representations should be improved. Finally, a review of the research on CS also permits us to examine the question of the impact of modality: does the development of a linguistic competence from a visual input rather than from an auditory input (with the same phonological content of the input) entail differences in the cognitive processes?

Previous work has already reviewed the data on the effect of exposure to CS on language acquisition and the development of cognitive architecture (Alegria, Leybaert, Charlier, & Hage, 1992; Leybaert, 1998; Leybaert, Alegria, Hage, & Charlier, 1998). Speech production has not been noticed to improve relative to that of deaf children using other language systems (Ryalls, Auger, & Hage, 1994), but important advantages have been noted in receptive language and in the degree to which language is organized neurologically. The chapter will thus be focused on the following issues: how is the information provided by the lips and by the hands integrated, and what are the possibilities for automatic systems of cueing? How are rhyming, remembering, and reading developed by deaf children using CS? Are the neural substrates involved in speech perception and in cued speech perception the same or different? Can CS provide useful information for cochlear implant users?

Cued Speech

Cued speech, developed by Orin Cornett in 1966, and adapted to more than 40 languages and major dialects (Cornett, 1994), is neither a sign language nor a manually coded system that uses signs from a sign language in a spoken-language word order. Instead, CS is a mode of communication for visually conveying traditionally spoken languages at the phonemic level (i.e., the same linguistic level conveyed via speech to hearing individuals). In CS, the speaker complements lip gestures of speech with manual cues. A cue is made up of two parameters: handshape and hand location around the mouth. The American English form of CS uses eight handshapes corresponding to groups of consonants and four hand locations to convey vowels and diphthongs. Phonemes that are distinguishable by lipreading are coded by a same handshape (like /p/, /d/, and /zh/) or at the same location. Conversely, phonemes that have similar lipshape are coded with different handshape (like /p/, /b/, and /m/) and hand location (like /i/ and /e/). Information given by the cues and information given by lipreading is thus complementary. Each time a speaker pronounces a consonant–vowel (CV) syllable, a cue (a particular handshape at a specific position) is produced simultaneously. For example, when saying the words "bell" and "bowl," two different hand locations would be used to distinguish between the two vowels; when saying the words "bat" and "pat," two different handshapes would be used to code the initial consonant. Syllabic structures other than CV are produced with additional cues. For example, a vowel syllable is represented by the neutral handshape at the hand placement corresponding to that vowel. Syllables including consonant clusters, or codas, are coded using the handshape corresponding to the additional consonant at the neutral position.

The handshapes and hand locations used in CS, unlike those of fingerspelling, are not, by themselves, interpretable as language. Instead, the visual information provided by lipreading is also necessary. The integration of labial and manual information points to a single, unambiguous, phonological percept that deaf children could not have achieved from either source alone. Deaf children are thus in a situation in which they can interpret the oral input as a reliable visual language in which the gestures (i.e., the combination of lip movements and manual cues) are now entirely specified, both at the syllabic and at the phonemic levels. For each syllable (and for each phoneme), there corresponds one (p. 278) (and only one) combination of labial and manual information, and vice versa, a characteristic that makes CS entirely functional for speech perception.

Two aspects of CS design are worth commenting on. First, the arbitrary decision to code the vowels by hand locations and the consonants by hand placements seems ecologically valid. Indeed, vowels have a longer duration on the acoustic level, which corresponds to the relatively long time required to pass from one location to another (see below). In contrast, consonants are relatively short events, and it is possible to get rapidly from one handshape to another. It is noteworthy that CS appears to honor this linguistically motivated distinction. Second, the possibility to transmit information about a consonant and a vowel in one single gesture allows a rapid rate of information transmission. Actually, the production of cues seems to slow the speech rate by about 30% (i.e., from 6 syllables per second to 4 syllables per second; Duchnowski et al., 1998a).

Effect of CS on Speech Perception

Deaf people's comprehension of spoken language is usually poor. Speechreaders understand only about one fourth of what is said even in dyadic conversations (Liben, 1978). Large improvement of deaf children's speech reception skills has been demonstrated when cues are added to lipreading both for English- and French-speaking children (Alegria, Charlier, & Mattys, 1999; Nicholls & Ling, 1982; Périer, Charlier, Hage, & Alegria, 1988). Nicholls and Ling (1982) found that the speech reception scores of profoundly deaf children taught at school with CS for at least 3 years increased from about 30% for both syllables and words in the lipreading alone condition to more than 80% in the lipreading-plus-cuescondition. Périer et al. (1988) showed that the advantage on sentence comprehension provided by the addition of cues was greater in children whose parents intensively used CS to communicate with them at home at an early age than in those children who benefited from CS later, and only at school, usually from the age of 6. This differential benefit displayed by the early and late-CS users may be explained in two ways: early CS-users might be more familiar with words presented in CS, and/or they might have a more efficient phonological processor, which depends of the quality of the mental representations of the phonemes.

In a study by Alegria et al. (1999), early CS users displayed a larger improvement related to the addition of cues both for word perception and for pseudo-word perception. Because pseudo-words were unfamiliar for both groups of subjects, these results support the idea that experience with CS enhances the efficiency of the processing of phonological information in early users.

Automatic Generation of Cued Speech

Given the good results provided by the use of CS on the reception of speech by deaf children, various systems of automatic generation of CS have been elaborated: the Autocuer, developed in the late 1970s (Cornett, Beadles, & Wilson, 1977; Duchnowski et al., 1998a), and an automatic cueing system based on automatic speech recognition (ASR) in real time (Duchnoswski et al., 1998a, 1998b). The discussion of these two systems allows one to have a clear understanding of the crucial variables to get an effective system.

The Autocuer consisted of a portable microprocessor-based device that analyzed the acoustic input, identified speech sounds, and assigned them to cues. The cues were then coded as patterns of illuminated segments projected for the receiver onto his or her eyeglasses. The cues were always delayed relative to the start times of the corresponding phonemes. It did not prove possible to develop an effective system that worked in real time.

Duchnowski et al.'s (1998a) prototype automatic cueing system involves two personal computers. The talker sits facing a video camera and wears a microphone. The first computer (PC1) preprocesses the acoustic waveform and handles capture of images of the talker. The second computer (PC2) performs phonetic recognition and produces the best matched cue sequence. The digital images are stored in PC1 memory for 2 seconds before superposition of a hand image corresponding to the cue identified by PC2 and playback on a monitor for the cue receiver. The artificially cued talker, as seen by the cue receiver, is thus delayed by 2 seconds relative to the real talker's actions. The authors observed that human cuers often begin to form a cue before producing the corresponding sound; therefore, they adjusted the start times of the cues to begin 100 msec before the boundary determined from acoustic data by the cue recognizer. They also found that the timing of the conversion from one handshape to the next was nearly optimal when cues changed halfway through the transition.

The automatic cueing system has been tested by asking young hearing adults with at least 10 years of manual CS experience to identify keywords presented in low-context sentences. Word scores averaged 90% for manual CS and only 66% for **(p. 279)** automatic cueing. However, the latter scores were much larger than the average 35% for speechreading alone. The automatic cueing system thus clearly improved subjects' comprehension. Future improvement of the system will include increasing the accuracy of the phoneme recognition by the automatic recognizer (which was of only 74%), the discriminability of the handshapes by using different colors, and the refinement of the synchronization of the cues to the talker's visible facial actions.

The timing of the beginning of the cue relative to the movement of the lips had not been documented until recently. Attina, Beautemps, and Cathiard explored this issue experimentally (see Attina, 2001). They videotaped a professional cuer producing CVCVCV sequences. They discovered that the hand gestures and the lip gestures are never really synchronized. The CS gesture starts about 200 msec. before the beginning of the lip movement corresponding to the syllable; the spatial location of the cue is reached at the beginning of the syllable and held during the production of the consonant. The next CS gesture is started during the beginning of the production of the vowel of the former syllable; the full production of the former vowel is reached before the next hand gesture reaches its location. As Duchnowski et al. (1998a) anticipated, Attina et al. also found that the CS hand gesture started before the sound.

These data suggest an interesting conclusion: it could be wrong to conceive the CS hand gestures as disambiguating lip gestures that were perceived simultaneously or even before by the receiver, because the lip gestures would be dominant compared to the hand gestures. Things may be more complex. It is possible that sometimes the lip gestures disambiguate the hand gestures, while sometimes the reverse occurs. If this speculation is true, it points toward a more integrated model of CS perception than a simple “lip gestures first, cues next,” at least for experienced CS receivers. (For a more detailed discussion on this point, see Alegria et al., 1992.)

Integration of Lipread and Manual Information in CS

The way information from manual cues and lipreading combine to produce a unitary percept has been explored by looking for phonological misperceptions induced by CS structural characteristics. These misperceptions might be substitutions based on the similarity between cues (i.e., perceiving /da/ for /zha/, which might result from the fact that /d/ and /zh/ share the same handshape) or intrusions of extra syllables in items requiring more CS units than they possess syllables (i.e., two CS units are required to code a single CCV or CVC syllable). Such misperceptions are potentially interesting because they might reveal the way CS is processed relative to lipread information. For example, to discriminate between /da/ and /zha/, it is necessary to pay attention to the lips posture. Using a task requiring identification of pseudowords produced in CS, it has been shown that the frequency of such misperceptions increased when CS was added to lipreading alone (Alegria et al., 1999). To further explore this issue, deaf youngsters were tested in a situation where lipread information was sometimes incongruent with CS information (i.e., the lipread syllable /va/ accompanied by the /p,d,zh/ handshape (Alegria & Lechat, 2005). It was expected that the perceptual system exposed to incongruous information would adopt phonological solutions that might reveal the weights it attributes to each source. Children who learned cued speech early and late were included in the experiment. The results showed that the total number of errors was greater in the late group. The proportion of CS misperceptions, however, was larger in the early group. In addition, the processing of incongruous cues was lower when lipread information was reliable than when it was not. In short, early CS users are more efficient in exploiting CS information, which is integrated with lipreading according to the salience of this latter information (Alegria, 2010).

The Development of the Three R’s: Remembering, Rhyming, and Reading

Remembering

Working memory is a fundamental system for human beings, a system that allows us to retain during a brief time stimuli that have been presented, in their order of presentation. Theories of working memory have emphasized the phonological nature of this process, meaning that memory trace has an acoustic or verbal basis in hearing people (Conrad & Hull, 1964). Baddeley and Hitch (1974) elaborated one of the most influential models of working memory. Their model postulates a peripheral storage system called the “phonological loop,” which is assumed to underlie performance in verbal working memory tasks. The phonological loop is divided into two components, a passive storage component (“phonological store”), into which auditory verbal material is registered, and an active rehearsal component (“articulatory loop”), which refreshes and maintains the information in the storage component. **(p. 280)** The “central executive” serves to allocate attention to these two systems. Auditory material is considered to have obligatory access to the phonological store, whereas visual material (written words, pictures) must be recoded via the articulatory loop before it is registered in the phonological store (Baddeley & Hitch, 1974). From the perspective of deaf children, the questions are: Can phonological representations be developed on the basis of visual information in the absence of reliable sound information? Would a phonological system developed on the basis of visual speech representations be totally parallel to a phonological system developed on the basis of auditory speech information?

Wandel (1989) was the first to investigate the effect of CS on the functioning of working memory. She used a procedure to evaluate hearing and deaf children's *internal speech ratio* (Conrad, 1979). The task was to memorize lists of printed words coming from two sets: rhyming words that were visually contrasted (e.g., *do, few, through, zoo*) and words visually similar that were not rhyming (e.g., *farm, lane, have*). The internal speech ratio (ISR) is the proportion of errors made on the rhyming set to the total number of errors on the two sets. An ISR greater than 52 indicates lower recall accuracy for rhyming lists than for visually similar lists. In contrast, an ISR lower than 48 results from more errors on the visually similar lists than on the rhyming lists and indicates the use of a visual code. In Wandel's study, the use of internal speech was significantly higher in deaf children exposed to CS (mean = 74.9) and in deaf children from the oral group (mean = 76.1) than in children from the total communication group (mean = 56.7). Exposure to CS thus enhances the development of the articulatory loop (Wandel, 1989).

Although the length of exposure to CS was not reported in Wandel's (1989) study, this variable seems critical in the development of the phonological loop. Indeed, children intensively exposed to CS before the age of 3 years, like age-matched hearing controls, show lower recall performance for rhyming than for nonrhyming lists of pictures (the phonological similarity effect) and lower recall performance for lists of multisyllabic words than for lists of monosyllabic words (the word length effect) (Leybaert & Charlier, 1996). In contrast, Leybaert and Charlier (1996) found that children exposed to CS only in their school environment (i.e., after the age of 6 years) did not show these effects, probably because they relied on a visual rather than on a phonological storage. The early CS users also had a larger memory span than the late CS users.

Following Baddeley's model, the phonological similarity effect and the word length effect arise from the articulatory rehearsal process, which is needed to convert pictures into phonological representations and to rehearse these representations. However, the above results leave open the question of the precise nature of this process. Indeed, rhyming words are also highly confusable in CS, because they share the same mouth shape as well as the same hand location for the vowel; similarly, multisyllabic words are also longer to produce in CS than monosyllabic words. The phonological similarity effect could be explained by the use of a rehearsal loop based on speech articulation; it is also compatible with a loop based on the use of CS articulators (i.e., mouthshapes, handshapes, and hand locations).

To address this issue, Leybaert and Lechat (2001a) examined the effects of rhyming, of mouthshape similarity, and of hand location similarity in an immediate serial recall task of stimuli presented in CS without sound. Subjects were youngsters exposed to CS with various intensity (low, medium, and high). The high group had received CS early and at home; the low group had been exposed to CS only late, at school; and the medium group had received CS at home, but inconsistently. Lists of words that sound similar and that are similar in CS provoked poorer recall than lists of phonologically dissimilar words in all three subgroups. This result confirms that hearing speech is not necessary to develop a sensitivity to the phonological rhyming effect. In addition, the deaf CS users exhibited poorer recall for lists of words similar in mouthshape (rounded lips) but which are different acoustically and are produced with different hand locations than for control lists dissimilar in mouthshapes, suggesting that the code in which information is handled in the phonological store includes the mouthshape gestures. Lists of words similar in hand location (at the corner of the lips), but not in sounding nor in mouthshape, also yielded poorer memory performance compared to control lists dissimilar in hand location, suggesting that an effect of similarity in hand location is also tied to the phonological storage buffer. The effect of hand location similarity was more important quantitatively (but not significantly) in the group with high exposure to CS, indicating that the phonological units handled by the phonological store arise in response to early linguistic experience. One may thus conceive that visual speech material has obligatory access to a visual phonological store, where it has to be refreshed and maintained by a CS rehearsal articulatory mechanism.

(p. 281) We searched for further support for this notion by investigating immediate serial recall of the same materials by hearing participants who learned CS for professional purposes or to use it with their deaf child. No effect of hand location similarity was found in these subjects, which is consistent with the idea that this effect is due to the fact that deaf subjects' phonological loop uses the same elements as those that contribute to speech perception. In contrast, the effect of mouthshape similarity was observed in these hearing adults, consistent with the notion that mouthshapes make up part of the speech perception device of hearing adults (McGurk & MacDonald, 1976).

These findings thus indicate some equivalence between the articulatory loop and the CS loop (i.e., the phonological [rhyming] similarity effects). But not all results indicate complete equivalence between these two loops: deaf subjects seemed to code hand location, whereas hearing CS users did not. Articulation is used to repeatedly feed information back into the storage buffer before it fades. In the case of lists of rhyming words, the traces left by spoken articulation and by CS articulation are highly confusable. In the case of lists of words articulated at the same hand location, the traces left by CS articulation are confusable for deaf participants only. It has been argued that the ease of imitating or rehearsing is a hallmark of the type of information that will allow for the development of the phonological loop (Reisberg & Logie, 1993; Wilson & Emmorey, 1998). The CS signal allows imitability or rehearsability to occur. These learned motor patterns thus may constitute the basis in the development of a CS-based rehearsal mechanism.

Rhyming

The abilities to judge that two words rhyme and to produce rhyming words in response to a target are among the first expressions of children's ability to appreciate the phonological structure of spoken language. In hearing children, the ability to produce and judge rhymes spontaneously is already present between 2 and 3 years of age (Read, 1978; Slobin, 1978), with some individual differences linked to the quality of their oral productions (Webster & Plante, 1995). Rhyming ability usually emerges spontaneously as a result of natural linguistic development and before any contact with literacy (Morais, Bertelson, Cary, & Alegria, 1986). Do the children who have acquired language skills via exposure to CS also have explicit metalinguistic abilities to reason about spoken language as an abstract symbolic system? Results from the reading literature suggest that metaphonological awareness, including rhyming, is a strong predictor of early reading success (Bradley & Bryant, 1978). Is the same relationship true of deaf children exposed to CS?

At present, few studies have been carried out on metaphonological abilities in deaf children exposed to CS. In one study, Charlier and Leybaert (2000) asked children to decide whether the names of pairs of pictures rhyme. Deaf children exposed early and prelingually to CS at home achieved a high level of performance, similar to that of the hearing controls, and better than the level achieved by other deaf children educated orally or with sign language. Besides the difference in general level of accuracy, the group of early CS users also differed from the other deaf children regarding the effect of two variables. First, unlike the other deaf children, the early CS users were not influenced by word spelling when they had to decide if two pictured words rhyme. This indicates that they rely on genuine phonological information rather than on orthographic information. Second, although all deaf children were misled by pairs of nonrhyming pictures with names similar in speechreading, the performance of the early CS users was less impaired by this variable than that of the other groups.

It thus seems that early exposure to CS allows the development of more precise phonological representations, which, in turn, assists in the emergence of accurate rhyming abilities. Finally, in early CS users, but not in other deaf children, the ability to judge rhymes is present before learning to read, as is the case in hearing children. How is this early metalinguistic ability related to early reading success, and is it related to the use of phonological recoding in written word recognition?

These are two topics that are being explored in a longitudinal study carried out by Colin, Magnan, Ecalle, and Leybaert (2007; see also Colin, Leybaert, Ecalle & Magnan, 2008). One aspect of their study involves rhyme judgment and rhyme generation tasks in nursery-school children and written word recognition tasks in first grade by deaf children having CS at home. The participants were deaf children educated with CS both at home and at school, deaf children who used CS at school only, orally educated deaf children, and hearing controls. A significant correlation was found between deaf children's performance in rhyming and word recognition tasks. Children with early phonological skills, particularly early CS users, performed better in the written word recognition tasks than the other deaf (p. 282) children, as did hearing children. Early exposure to CS seems to allow a good integration of phonological contrasts before learning to read and consequently the development of accurate phonological representations that are essential for establishing an efficient grapho-phonemic assembling process.

Another way to evaluate rhyming abilities is to ask children to generate rhymes in response to written or pictured target words. Charlier and Leybaert (2000) reported that early CS users, like hearing children matched for reading level, achieved a high level of accuracy and produced a high percentage of correct responses that are orthographically different from the target (e.g., BLUE–few). These results contrasted with those of children exposed only late to CS who achieved only a limited level of accuracy and produced mainly words orthographically similar to the target rhyme (e.g., BLUE–glue). This indicates that early CS users relied more on phonological information, whereas late CS users used more orthographic information to generate rhymes. However, the accuracy of early CS users was slightly lower than that of their hearing controls, and the CS users were more affected than the hearing by the orthography-to-phonology consistency. They generated more correct responses for rhymes that have consistent pronunciations, meaning a single pronunciation (like—EEL or—OTE in English: all words ending with—EEL share the same rhyme pronunciation), than for rhymes having inconsistent (different) pronunciations (like—ERE, which has a different pronunciation in “MERE” and “WERE,” or the rhyme—OOD, which is pronounced differently in “WOOD” and “BLOOD”). For some targets with inconsistent rhymes, deaf children, including early CS users, may have stored incorrect phonological representations that were derived from the spelling of the word.

The elaboration of phonological representations from spelling is not specific to deaf children: experience with the alphabetic orthography provides information that enhances the internal representations of speech segments in hearing children, too (Ehri, 1984). However, orthography might be more important for deaf children (Leybaert & Alegria, 1995), including deaf children exposed to CS.

The results of the Charlier and Leybaert (2000) rhyme generation task were replicated in English, on a sample of postgraduate deaf students who did not use CS (LaSasso, Crain, & Leybaert, 2003). This latter study also demonstrated a relationship between deaf children’s reading ability (measured by the Stanford Achievement Test score) on one hand, and the ability to generate correct responses to targets with inconsistent rhymes, as well as the ability to generate correct responses orthographically different from the target on the other hand. Taken together, these results are highly consistent with the notion that metaphonological awareness is related to reading success in deaf children as it is in hearing children, in English language as it is in French (see also Crain & LaSasso, 2010).

Reading and Spelling

One of the main academic challenges encountered by deaf children is learning to read. Statistics are clear: the median reading comprehension scores of deaf and hard-of-hearing students in the Stanford 9 (SAT9) norming for ages 8–18 all fall below the median scores for hearing students at grade 4 (Traxler, 2000). This confirms previous data obtained by Conrad (1979), who found that only 5 deaf young adults out of 205 (2.4%) with hearing loss greater than 85 dB achieved a reading level corresponding to their chronological age. Apparently, a primary reason for such lags is that deaf children do not know oral language before learning to read. When they encounter a new word in their reading, they are completely lost because even if pronounced, that word does not activate anything in their mental lexicon. This is not the case for hearing children who can apply grapheme-to-phoneme correspondences to derive the pronunciation of a new sequence of letters. This pronunciation then activates the meaning of the word.

It thus seems necessary to have, before learning to read, a set of phonological representations that could be accessed from the printed words (by grapheme-to-phoneme rules) and that are linked to semantics. For hearing children, these may include how the word sounds, how it is pronounced by the vocal articulators, and how it looks on the lips. From the perspective of deaf children, the questions are: Would the phonological representations issued from visual perception allow learning to read by means of the usual grapheme-phoneme translation process? What level of reading achievement can be expected for deaf children educated with CS?

Wandel (1989) was the first researcher who compared the reading level (measured by the SAT reading comprehension scaled scores) of a deaf CS group with other deaf groups and a hearing group. She found that the CS and the oral groups attained higher reading scores than a total communication group. However, the reading level achieved by the CS group in her study was lower than that of the (p. 283) hearing controls. Data obtained in our studies indicate that the degree of exposure to CS is a critical variable. Children exposed early to CS attained reading levels comparable to those of hearing children of the same age, but children exposed only late to CS and children educated with sign language displayed the well-known delay in reading achievement (Leybaert, 2000; Leybaert & Lechat, 2001b).

Do early CS users learn to read and to spell using procedures similar to hearing children? Recent research has focused on the use of phonology-to-orthography correspondences in word spelling. One of the clearest indicators of the use of this procedure is the presence of phonologically accurate errors. The occurrence of errors like “brane” for “BRAIN” indicates that children have precise phonological representations, use phoneme-to-grapheme translation rules, and do not know the word-specific orthographic form. Most of the spelling errors made by hearing spellers are of this type.

In a first study Leybaert (2000) found that these types of errors were also made by early CS users. In contrast, late CS users made a lower proportion of phonologically accurate spellings and more phonologically inaccurate spellings (e.g., “drane” for “BRAIN”), which likely reflects inaccurate phonological representations, in which the identity of each phoneme is not clearly defined. The late CS group also made more transposition errors (e.g., “sorpt” for “SPORT”), which did not preserve the phonetic representation of the target word. However, in this study, intensive CS exposure was confounded with the total amount of language exposure. Early exposure to a fully accessible language may be the critical factor, rather than exposure to CS per se. Therefore, in a second study Leybaert and Lechat (2001b) compared the spelling of the early CS users to that of deaf children exposed early in life to a visual language, albeit of a different nature (i.e., sign language). The results were clear-cut: only the hearing children and the early CS users showed evidence for predominant use of phoneme-to-grapheme correspondences when they did not know how to spell a word (see also Colin, Leybaert, et al., 2007; Colin, Magnan, et al., 2008).

Alegria, Aurouer, and Hage (1997) also collected evidence regarding the phonological processes used by deaf children to identify written words encountered for the first time. The experiment involved leading children to elaborate phonological representations of new words during a lesson in which they were taught to associate drawings with their names via lipreading or lipreading plus CS. Before and after the lesson, each drawing was presented accompanied by four written alternatives: the correct one and three pseudowords, one of the latter being a strict lipread foil of the correct response (e.g., “prain” for “BRAIN”). Important and reliable increases in performance from the pre- to the post-test were observed in all cases, indicating that when a deaf child faces a new written word, he or she is able to identify it. The improvement in scores from pre- to post-tests were greater when CS was used during the lesson, indicating that the accuracy of the phonological representations of words was greater in this case. This improvement was larger in early than in late CS users. A post-test 7 days after the lesson revealed that the phonological information stored during the lesson remained available in the early CS group but had disappeared in the late CS group.

To conclude, the nature of the child’s early linguistic experience plays a significant role in predicting reading and spelling outcomes. Early and intensive exposure to a system that makes all phonological distinctions of spoken language visually accessible seems critical to ensure adequate spelling and reading development. A late and less intensive exposure to systems such as CS does not have the same effect on the use of phoneme-to-grapheme correspondences.

Hemispheric Specialization

The differences between early and late CS users regarding linguistic, metalinguistic, and working memory developments could come from differences regarding the specialization of the left hemisphere for linguistic processing (Leybaert, 1998; Leybaert & D’Hondt, 2003. This hypothesis is grounded in several lines of evidence. First, lateralized cerebral function for speech perception develops during the first 3 years of life of hearing children and seems more dependent on linguistic experience than on chronological age per se (Dehaene-Lambertz, Christophe, & Van Ooijen, 2000; Mills, Coffey-Corina, & Neville, 1993, 1997). Second, it has been argued that while the initial storage of utterances mainly depends on resources located in the right hemisphere, the analytical language processes developing around the age of 2 years would reside in the left hemisphere (Locke, 1998).

According to Locke (1998), “children who are delayed in the second phase have too little stored utterance material to activate their analytic mechanism at the optimum biological moment, and when sufficient words have been learned, this modular capability has already begun to decline” (p. 266). (p. 284) It might thus be the case that early CS users have stored many perceptually distinct utterances in CS in the first years of life, which would allow the analytical mechanism, housed in the left hemisphere, to work at the appropriate period. In contrast, in the late CS users who have passed the first critical years in linguistically deprived situations, the initial bias for left hemisphere specialization for language may have disappeared.

Thus far, there has been no direct evidence of the changes in left hemisphere specialization as deaf children acquire their primary language, similar to what has been found in the case of hearing children. Studies reported so far generally used the visual hemifield paradigm. This paradigm is based on the anatomy of the human visual system. The nerve fibers carrying information about stimuli presented in the right visual hemifield (RVF) project to the visual cortex of the left cerebral hemisphere, whereas the fibers carrying information about stimuli presented in the left visual hemifield (LVF) project to the visual cortex of the right cerebral hemisphere. Provided that a person is forced to fixate on the center of the presentation screen, it is thus possible to present words to the desired hemisphere. An RVF advantage for linguistic processing of stimuli would attest a superiority of the left hemisphere for that processing.

Neville (1991) has proposed that full grammatical competence in a language determines the left hemisphere specialization during processing of that language. In a hemifield study requiring the identification of written words, Neville found that while hearing subjects showed behavioral and electrophysiological left hemisphere lateralization, deaf subjects who has acquired ASL as their first language did not. Most of them had not acquired full grammatical competence in

English, and this may be the reason they did not display left hemisphere specialization during reading. More direct evidence for this conjecture was obtained in a study of event-related brain potentials (ERP) during sentence reading. ERPs elicited by closed-class words (function words, prepositions, adverbs) displayed a peak that was most evident over the left hemisphere, indexing grammatical processing. This specific response was absent from the ERPs of deaf subjects who scored lower on tests of English grammar than did the hearing subjects, but was present in deaf subjects who scored nearly perfectly on the tests of English grammar (Neville, 1991). These data thus support the idea that the acquisition of grammatical competence in a language is a necessary condition for the development of left hemisphere specialization for that language.

Early and intensive exposure to cued speech could provide the conditions for the development of grammatical competence in oral language (Hage, Algeria, & Périer, 1991). If this is the case, early CS users would display clear evidence for left hemisphere specialization for the processing of written and CS languages; late CS users, who do not have a fully grammatical competence in oral language, may have an atypical development of cerebral dominance for language processing.

D'Hondt and Leybaert (2003) compared the lateralization pattern of CS users for the processing of written stimuli to that of hearing subjects matched for reading level, sex, and linguistic competence. Subjects had to compare a stimulus presented at the center of the screen (hereafter "central") to a stimulus presented for 250 msec. in the left or right visual hemifield (hereafter "lateral"). Three tasks were used, including two linguistic tasks and a nonlinguistic one. The nonlinguistic task involves visual judgment: are "EeeE" (central stimulus) and "Eeee" (lateral stimulus) the same or not? No linguistic processing is required to perform this task, which could entail a similar performance of both hemispheres or even an advantage of the right hemisphere (Pugh et al., 1996). No difference between deaf and hearing subjects was observed.

One linguistic task involved semantic judgments: do "cat" (central stimulus) and "rabbit" belong to the same semantic category? A right visual field (left hemisphere) advantage was observed for this semantic decision task in deaf as in hearing subjects, matched for their ability to do semantic judgments in a control test (both groups reached 95% correct responses in a paper-and-pencil task). This result supports Neville's hypothesis: subjects with a full grammatical competence in French language displayed left hemisphere specialization for reading that language. The other linguistic task involved rhyming judgment of orthographically dissimilar pairs: do "feu" and "noeud" rhyme (in English, do "blue" and "few" rhyme)? In hearing subjects, an RVF advantage (left hemisphere) was observed, confirming data in the literature (Grossi, Coch, Coffey-Corina, Holcomb, & Neville, 2001; Rayman & Zaidel, 1991). Surprisingly, however, no hemifield advantage was observed in the CS users. The lack of significant laterality effect in the Deaf could be related to their limited rhyming ability, indicated by their results on the paper-and-pencil test (the Deaf achieved 88% correct responses, the hearing **(p. 285)** achieved 94%). Alternatively, the neural resources activated during rhyme judgment may be different in deaf CS users from those activated in hearing subjects.

This suggestion has been confirmed through an fMRI experiment which compared a group of French, orally educated deaf students (non-CS users) and a group of hearing students on a rhyming task (Aparicio, Gounot, Demont, & Metz-Lutz, 2007). Results showed a greater activation in right inferior frontal gyrus areas in the deaf students, a difference that remained even when the differences in rhyming task performance between the two groups was taken into account. Aparicio et al. suggested that significant differences in activation might reflect different cognitive strategies. Alternatively, the neural mechanisms of phonological processing may be shaped by the auditory experience of speech, greater in the hearing students than the deaf students (even with assistive listening devices).

This latter suggestion was based on the results of MacSweeney et al. (2001), who showed that congenitally deaf individuals whose first language was spoken English showed significantly less left temporal activation than hearing subjects when performing a simple speechreading number task. These authors suggested that "hearing speech helps to develop the coherent adult speech perception system within the lateral areas of the left temporal lobe" (p. 437). The comparison between activation displayed by CS users to that displayed by the deaf non–CS users and by the hearing may shed light on this issue.

Consider next the lateralization of those aspects of processing that are directly dependent on perceptual processing. Leybaert and D'Hondt (2003) asked whether linguistic processing of CS stimuli might be better performed by the left hemisphere (LH), while nonlinguistic processing of the same stimuli entail no hemispheric advantage, and whether the left hemisphere advantage for linguistic processing is modulated by the age at which deaf children receive formal linguistic input.

Subjects had to compare a centrally presented video (the standard) to a video presented next, and very briefly, in the left or the right visual hemifield (the target). In the linguistic condition, they had to decide whether the same word in CS was produced in the two videos, independently of the hand that produced the stimuli. In the nonlinguistic condition, they had to decide whether the cue was produced with the same hand, independently of the word produced. A sample of subjects with early exposure to CS was compared to a sample of subjects with late exposure to CS. The results were clear-cut: in the linguistic condition, the early CS group showed an accuracy advantage for stimuli presented in the right visual field (LH), whereas the subjects of the late CS group did not show any hemifield advantage. In the nonlinguistic condition, no visual advantage was observed in either group (Leybaert & D'Hondt, 2003). These results confirmed the previous finding that the left cerebral hemisphere is specialized for language, regardless of the nature of the language medium (Emmorey, 2002). They also suggest that the neural systems that mediate the processing of linguistic information are modifiable in response to language experience. The LH superiority for language processing appears more systematically in children exposed early to a structured linguistic input than in children exposed only late to this input.

It also would be worthwhile to investigate neuronal activity when deaf, early CS users are processing words presented in CS. At the time of writing, three hypothesis related to this issue arebeing tested in our laboratory with the fMRI technique. We hope they will shed light on the linguistic strategies used by deaf early CS-users and their underlying brain functioning.

First, is activation of cerebral regions similar or different to hearing users when they perceive audio-visual speech? More precisely, does CS activate "auditory cortex" in the temporal lobes with a preference for the left hemisphereas in AV and Sign Languages? This will confirm the idea that this brain area is part of a 'core language system' that is not affected by modality

A second interesting question is to investigate how cues (alone) are processed in the brain. As it was already mentioned in this chapter, CS was created by Cornett in order to be able to perceive clear and full phonetic information of the oral language (Cornett, 1967). In order to do that, Cornett invented different hand shapes and hand positions (i.e. the cues) conveying linguistic information. These cues were not naturally created by users in an ecological context as it happens with other visual languages - see the example of Sign Language of Nicaragua (Senghas et al 2004). On the contrary, cues are fully "artificial". For Cornett, the intended role of these cues was to disambiguate lip reading. However, cues (i.e. hand gesture and hand positions) start to be produced before the lip reading movement corresponding to the syllable (Attina, 2001). Therefore, it seems that CS users have inversed the original intention of Cornett producing the "artificial" cues **(p. 286)** *before* producing the "natural" speech with the lips. Therefore, it seems that the linguistic information given by the cue will be completed after by lipreading (Attina, Gibert, Cathiard, Bailly, & Beautemps, 2010). Does it mean that the receptor is capable to process much of the linguistic and phonetic information contained in the oral message just by perceiving the early "artificial" cue (before lip reading comes up)? Indeed, if much of the phonetic and linguistic information of the CS is already processed during early perception of the "artificial" cue, then the patterns of neuronal activation are expected to be similar in cues and in CS.

Our third question concerns CS integration. Neither cues alone nor Lip reading alone conveys all the necessary linguistic information to decode oral message. Indeed, perceiving CS means also to integrate information coming from both speech signals, the cues and the lipreading. But how is this integration processed in the brain? Is it similarly processed to the AV integration? Integration in AV[1] has been found to be linked to activation in left posterior superior temporal sulcus (pSTS) (Calvert et al, 2000, Callan et al, 2004). The role of pSTS would be related to the analysis of dynamic features of visual speech and heard speech that make possible the integration (Campbell, 2008). However, another region located in the occipito-temporal junction (at MT/V5) seems to be also related with audio-visual integrationduring speech (Jones & Callan, 2003). Moreover, bilateral MT/V5 will be particularly activated when the auditory component of the speech is hard to hear and the visual influence of the speech is much stronger (Sekiyama et al, 2003). In CS, there is no multimodal integration as in AV speech but rather an integration of visual multisignal speech components (cues and LR). Will integration of CS occur in the MT/V5 region instead of pSTS? This would suggest that MT/V5 might be also a site of speech integration within visual speech signals.

Summary and Conclusions

At the time of this review, new research questions that go beyond the issues of efficacy of CS are emerging. First, besides strong similarities between deaf CS users and hearing children, differences remain. CS users seem more dependent on word spelling than hearing subjects in rhyme generation; their phonological loop for processing CS information seems sensitive to hand location, a phonological feature in CS; and they do not display an LH advantage for rhyme judgment. Whether these differences could be explained by a common factor remains to be explored. It is also possible that functionally similar processes rely on different neural resources. The study of the cerebral regions activated by the processing of CS information, compared to audio-visual information, is on our research agenda (Aparicio, Peigneux, Charlier, & Leybaert, in preparation).

A second issue that remains to be investigated is the source of individual differences. Cued speech has sometimes been supposed to be difficult in the receptive mode. This does not seem to be true for our early CS users, but it may be true for others. One obvious variable explaining the differences is intensity of exposure. Beside this, the notion of a sensitive period might be relevant here. The benefit provided by early exposure to CS may be related to the level of cortical activity in the visual cortex, which peaks around the age of 5 years (Neville & Bavelier, 2001). It might be more difficult for deaf children to process CS information effortlessly at a later age. The question of a critical or sensitive period for CS acquisition remains to be addressed.

A final topic that urgently deserves research is the benefit afforded by CS exposure to the use of cochlear implants. Collaboration rather than competition is likely here. Theoretically, it is possible that the child exposed to CS creates phonological representations that are exploitable later when the nervous system is stimulated by the electric signal delivered by a cochlear implant. It is asserted that a cochlear implant gives only degraded acoustic information, which makes it difficult to reliably discriminate fine phonetic differences in place and voicing features (Pisoni, 2000). The use of CS may help to set these fine phonetic differences (Hage & Leybaert, 2006; Leybaert & LaSasso, 2010). This leads one to predict that profoundly deaf children who are CS users would get better results in auditory word identification than those who are not CS users. Clinical evidence supports this hypothesis, which needs to be tested experimentally (Fraysse, Ben M'Rad, Cochard, & Van, 2002). Speech production might be another ability where the informations provided by CS and by the implant can converge. Children who receive auditory feedback through an implant may adjust their oral productions in relation to the reference points created by CS.

To conclude, CS has already afforded important benefit for language development of deaf children since its creation 30 years ago. With the new (p. 287) technologies available (e.g., automatic generation of CS, cochlear implants), new benefits may be foreseen.

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Notes:

(1) Regions of AV integration are obtained comparing activation in AV to unimodal auditory and unimodal visual.

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