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AVSP 2003 - International Conference
on Audio-Visual Speech Processing
St. Jorioz, France
September 4-7, 2003

The role of Cued Speech in language processing by deaf children : An overview

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Abstract

Cued Speech (CS) is a system of manual cues that combined to the lipread information conveys visually the traditionally-spoken languages at the phonemic level. It is argued here that exposure to CS allows deaf children to develop accurate phonological representations which can support rhyme judgment, phonological short-term memory, use of grapheme-to-phoneme correspondences in reading and spelling. Strong differences systematically appear between those children who have been exposed early and late to CS, suggesting that early exposure induces the development of left hemisphere specialization for language processing. The question of contribution of CS to linguistic development of children fitted with cochlear implant is discussed.

1. Introduction

Despite normal intelligence and normal potential of learning, children born profoundly deaf generally exhibit lags across the board in 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 deficits lies in the deaf children's reduced access to oral language through lipreading.

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 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.

In order to help deaf children to perceive through the visual channel the information about the phonological structure of spoken language, different systems have been elaborated. One of this system is Cued Speech (CS) (Cornett, 1967).

2. Cued Speech

CS, 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 of two parameters : hand shape and hand location around the mouth. The French form of CS (called Langage Parlé Complété, or LPC) uses eight hand shapes corresponding to groups of consonants and five hand locations to convey vowels and diphtongs. Phonemes that are well distinguishable by lipreading are coded by a same handshape (like /p/, /d/ and /ʒ/) or at the same location. Conversely, phonemes that have similar lip shape are coded with different hand shape (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 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 V 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 are not, by themselves, interpretable as language. Instead, the visual information provided by lipreading is also necessary. 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. At each syllable (and at each phoneme) corresponds one (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 to pass from one location to another (see below). By contrast, consonants are short events, and it is possible to get rapidly from one handshape to another. It is noteworthy that CS appears to honour 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.

3. 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 when cues are added to lipreading has been demonstrated both for the English- and the 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 three years increased from about 30% for both syllables and words in the lipreading alone condition to more than 80% in the lipreading + cues condition. 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 six. The superior benefit displayed by the early CS users may be explained either by their greater familiarity with words presented in CS, and/or by a more efficient phonological processor, which depends of the quality of the mental representations of the phonemes. In a recent study (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 pseudowords 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.

4. Automatic generation of CS

Given the good results provided by the use of Cued Speech on the reception of speech by deaf children, various systems of automatic generation of Cued Speech have been elaborated : the Autocuer, made 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 which analysed the acoustic input , identify speech sounds and assign them to cues. The cues were then coded as patterns of illuminated segments projected for the receiver onto his/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, 1998b) prototype automatic cueing system comprised two PCs. The talker sits facing a video camera and wears a microphone. The PC1 pre-processes the acoustic waveform and handles capture of images of the talker. The PC2 performs phonetic recognition and produces the best-matched cue sequence. The digital images are stored in PC1 memory for two

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).

seconds prior to 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 two 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 change halfway through the transition. The automatic cueing system has been tested asking young hearing adults with at least ten years of manual CS experience to identify keywords presented in low-context sentences. Word scores averaged 90% for manual CS, for 66% only for 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 included increasing of the accuracy of the phoneme recognition by the automatic recognizer (which was of only 74%), of the discriminability of the handshapes by using different colors, and of 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 was not documented up to now. Attina, Beautemps and Cathiard recently explored experimentally this issue (Attina, Beautemps & Cathiard, 2002). 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 hold 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. anticipated it, they also found that the CS hand gesture started before the sound.

These data suggest that 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, 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.

5. Integration of lipread and manual information in CS

The way information from manual cues and lipreading combine to produce an unitary percept has been explored 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 /ʒa/ which might result from the fact that /d/ and /ʒ/ share the same handshape) or intrusions of extra-syllables in items requiring more CS units that 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, in order to discriminate between /da/ and /ʒa/ 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 increases when CS was added to lipreading alone (Alegria et al., 1999). To further explore this issue deaf youngsters were submitted to a situation where lipread information was sometimes incongruent with CS information (i.e. the lipread syllable /va/ accompanied by the /p,d,ʒ/ handshape (Alegria & Lechat, in prep.). It was expected that the perceptual system exposed to incongruous information will adopt phonological solutions which might reveal the weights it attributes to each source. Early and late CS-users 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. To conclude, early CS-users do exploit more efficiently CS information, which is integrated with lipreading according with the salience of this latter information.

6. The development of the three R 's : remembering, rhyming, and reading

6.1. Remembering

Working memory is a fundamental system for human beings, a system that allows us to retain during a brief time the 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 model of working memory. Their model postulates a peripheral storage system termed 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, into which auditory verbal material is registered, and an active rehearsal component, which refreshs and maintains the information in the storage component. The "central executive component" serves to allocate attention to these two systems. Auditory material is considered to have obligatory access to the phonological store, while visual material (written words, pictures) must be recoded via the articulatory loop before it is registered in the phonological store (Baddeley & Hitch, 1974).

Wandel (1989) was the first researcher 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 which were visually contrasted ("do", "few", "through", "zoo", …) and words visually similar which were not rhyming ("farm", "lane", "have"…). The internal speech ratio (ISR) was the proportion between errors made on the rhyming set and 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. By contrast, an ISR lower than 48 results from more errors at the visually similar lists than at 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 = 76) than in deaf children from the Oral group (mean = 74) or from the Total Communication group (mean = 57). However, the ISR of the Cued Speech group seems lower than that of the Hearing group (mean = 79), although this difference was not tested. Exposure to CS thus enhances the development of the articulatory.

While the degree of exposure to CS was not reported in Wandel' study, this variable seems critical in the development of the phonological loop. Indeed, children intensively exposed to CS before the age of 3 years showed, like age-matched hearing controls, lower recall performance for rhyming than for non-rhyming 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). By contrast, 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, these two effects arise from the articulatory rehearsal process itself, which is needed to convert pictures into phonological representations and to rehearse these representations. However, these 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 but it is also compatible with a loop based on the use of CS articulators, i.e. mouthshapes, hand shapes and hand locations.

To address this issue experimentally, we examined immediate serial recall of stimuli presented in CS, without sound. Subjects were youngsters exposed to CS with various intensity (Low, Medium, and High). The High group has received CS early and at home; the Low group has been exposed to CS only late, at school; the Medium group has received CS at home, but inconsistently. Lists of words that sound similar and similar in CS provoked poorer recall than lists of phonologically dissimilar words in all three sub-groups, confirming that hearing speech is not necessary to develop a sensitivity to the phonological rhyming effect. The deaf CS users also exhibited poorer recall for lists of words similar in mouthshape (rounded lips) but which are different acoustically and are produced with different hand placement 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 placement (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 placement, suggesting that an effect of similarity in hand placement is also tied to the phonological storage buffer. Suggestively, the effect of hand placement 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 (Leybaert & Lechat, 2001a). One may thus conceive that visual speech material have obligatory access to a visual phonological store, where it has to be refreshed and maintained by a CS rehearsal articulatory mechanism. Hearing participants who were CS-users did not shown any effect of hand location similarity, which is consistent with the notion that this effect is due to the fact that deaf subjects' phonological loop uses the same elements as those that contribute to speech perception.

Our findings thus indicate some equivalence between the speech loop and the CS loop, i.e. the phonological, rhyming, similarity effect. But not all our results indicate complete equivalence between these two loops : deaf subjects seemed to code hand location, while 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 imitability, or rehearsability 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 may constitute the basis in the development of a CS-based rehearsal mechanism.

6.2. 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 two and three years of age, 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).

A few studies have been carried out on metaphonological abilities in deaf children exposed to Cued Speech. In a recent study (Charlier & Leybaert, 2000), children were asked to decide whether the names of pairs of pictures rhyme. Deaf children exposed early and precociously 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 (see also LaSasso et al., 2003). Second, while all deaf children were mislead by pairs of non rhyming 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 turns, assist in the emergence of accurate rhyming abilities. Finally, in early CS-users, but not in other deaf children, the ability to judge rhymes was present before learning to read, as is the case in hearing children. Is this early metalinguistic ability related to early reading success, through the use of phonological recoding in written word recognition? This topic is currently explored in an ongoing longitudinal study by S. Colin. Thes study involved rhyme judgement and rhyme generation tasks in nursery school and written word recognition task in first grade by deaf children having CS at home, deaf children educated with CS at school only, orally-educated deaf children and hearing controls. A significant correlation appeared between deaf children's performance in the two experiments. Children with early phonological skills, particularly early CS-users, performed better in the written word recognition tasks than the other deaf children, as did also 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 which are essential for the establishment of an efficient grapho-phonemic assembling process (Colin, Magnan, Ecalle, & Leybaert, in prep.).

6.3. Reading and Spelling

One of the main problem 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 norming for ages 8 through 18 fall below the median scores for hearing students at grade 4 (Bloomquist Traxler, 2000). This confirms previous data obtained showing that only 5 young adults over 205 (5 %!) of the deaf with hearing loss greater than 85 dB achieved a reading level corresponding to their chronological age (Conrad, 1979). The main reason 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 in order to derive the pronunciation of a new sequence of letter. This pronunciation then activates the meaning of the word.

Wandel (1989) compared the reading level (measured by the SAT reading comprehension scaled scores) of deaf CS group with other deaf groups and a hearing group. She found that the Cued Speech and the Oral groups attained higher reading scores than the Total Communication group. However, the reading level achieved by the CS group in her study was lower than that reached by the hearing controls. Data obtained in our studies indicate that the degree of exposure to CS is a critical variable. Children exposed early and precociously to CS attained comparable reading level to that of hearing children of the same age, while children exposed only late at CS displayed the well-known delay in reading achievement (Leybaert, 2000; Leybaert & Lechat, 2001b).

Our recent research has focused on the use of phonology-to-orthography correspondences in word spelling. One of the clearest indicator of the use of this procedure is the presence of phonologically accurate errors. The occurrence of errors like *brane* for BRAIN indicate that children (a) have precise phonological representations, (b) use phoneme-to-grapheme translation rules, and (c) 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), we found that, as expected, this is also the case for early CS-users. By 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), that 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 & Lechat, 2001b), we 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.

We also collected evidence regarding the phonological processes used by deaf children to identify written words encountered for the first time. The experiment consisted in bringing 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 propositions : the correct one and three pseudowords, one of them being a strict lipread foil of the correct response (e.g. “prain” for BRAIN). Important and reliable increases of 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/she is able to identify it. The improvement score 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 made 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 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 like CS does not have the same effect on the use of phoneme-to-grapheme correspondences.

7. Hemispheric specialization

The differences between early and late CS users regarding linguistic, metalinguistic and working memory developments could come from differences regarding the specialisation of the left hemisphere for linguistic processing (Leybaert, 1998; Leybaert & D'Hondt, 2003). Neville has proposed that full grammatical competence in a language determines the left-hemisphere specialization during processing of that language (Neville, 1991). Early and intensive exposure to Cued Speech could provide the conditions for the development of grammatical competence in oral language (Hage, Alegria, & 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; by contrast, 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.

We explored these issued in a series of studies (D’Hondt, 2001). In a first study, the lateralization pattern of CS-users for the processing of written stimuli was compared to that of hearing subjects matched for reading level, sex, and linguistic competence (D'Hondt & Leybaert, 2003). Subjects had to compare a stimulus presented at the center of the screen (hereafter: central) to a stimulus presented next for 250 msec. in the left or right visual hemifield (hereafter : lateral). Three tasks were used, among which two linguistic tasks and a non-linguistic one. The non-linguistic task involves visual judgement : 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 judgements : 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 judgements 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 judgement of orthographically dissimilar pairs: do FEU and NOEUD rhyme (in English : do BLUE and FEW rhyme)? In hearing subjects, a RVF advantage (left hemisphere) was observed, confirming data of the literature (Grossi, Coch, Coffey-Corina, Holcomb, & Neville, 2001; Rayman & Zaidel, 1991). Surprisingly, no hemifield advantage was observed in our CS-users. It is possible that the neural resources activated during rhyme judgment are different in deaf CS-users from those activated in hearing subjects. Data from connected research suggest that the areas activated during speech-reading are not as left-lateralized in deaf people as they are in hearing people, which suggests that “*hearing speech helps to develop the coherent adult speech perception system within the lateral areas of the left temporal lobe*” (MacSweeney et al., 2001, p. 437).

The lateralisation of those aspects of the processing that are directly dependent on perceptual processing was also investigated by D’Hondt. Two questions were addressed : Does linguistic processing of Cued Speech stimuli be better performed by the left hemisphere, while non-linguistic processing of the same stimuli entail no hemispheric advantage ? Is the left hemisphere advantage for linguistic processing modulated by the time in their

development at which deaf children received 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 Cued Speech was produced in the two videos, independently of the hand which produced the stimuli. In the non-linguistic 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 obtained an accuracy advantage for stimuli presented in the right visual field, while the subjects of the late-CS group did not show any hemifield advantage. In the non-linguistic condition, no visual advantage was observed in either group (Leybaert & D'Hondt, 2003). These results confirmed the already existing evidence 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 left hemisphere 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.

8. Conclusions : terra incognita

At the term of this review, new research questions that go beyond the issues of efficacity of CS, emerge. First, besides strong similarities between deaf CS-users and hearing children, differences remain (f.i. in the lateralization pattern for rhyme judgement). The study of the cerebral regions activated by the processing of Cued Speech information, compared to audio-visual information, is on the agenda (Eden, Cappell, La Sasso, & Zeffiro, 2001).
A second issue that remains to be investigated is the source of individual differences. CS has sometimes been supposed to be difficult in the receptive mode. This does not seem to be true for our early CS-users, but may be true for others. One obvious variable explaining the differences seems intensity of exposure. Beside this, the notion of 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 effortless 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 implant. Collaboration rather than competition is very likely here. Theoretically, it is possible that the child exposed to CS creates phonological representations that are exploitable when the nervous system is stimulated by the electric signal delivered by the CI. It is asserted that CI gives only a degraded acoustic information, that makes difficult to reliably discriminate fine phonetic differences in place and voicing features (Pisoni, 2000; Giraud et al., 2001). The use of CS may help to set these fine phonetic differences. This leads one to predict that profoundly deaf children who are CS-users would (a) benefit from stimulations combining electric auditory information and visual information delivered through CS, and (b) would even get better results in auditory word identification than those who are not CS-users. Preliminary evidence support these hypotheses, which need to be tested experimentally (Leybaert et al., 2002; 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 the 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 technologies available (automatic generation of CS, cochlear implants), new benefits may be foreseen.

9. Acknowledgements

This paper is largely based on a chapter published in The Handbook of Deafness , edited by M. Marschark & P. Spencer (2003), with permission of Oxford University Press, 2003. Requests of reprints should be addressed to J. Leybaert, Université libre de Bruxelles, LAPSE, CP 191, 50, avenue F.D. Roosevelt, B-1050 Brussels, Belgium. Fax : 32 2 650 22 09. e-mail : leybaert@ulb.ac.be

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