Impact of Cued Speech on audio-visual speech integration in deaf and hearing adults

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Abstract

For hearing and deaf people, speech perception involves an integrative process between auditory and lip read information. In order to disambiguate information from lips, manual cue may be added (Cued Speech). We examined how audio-visual integration is affected by the presence of manual cues. To address this issue, we designed an original experiment using audio-visual McGurk stimuli produced with manual cues. The manual cue was either congruent with auditory information, lip information or with the expected fusion. Our results suggest that manual cues can modify the audio-visual integration, and that their impact depends on auditory status.

Index Terms: Deafness, Cued Speech perception, Cochlear implant, Binaural hearing aids, Multi signal integration

1. Introduction

In face-to-face communication, speech perception is a multimodal process involving both auditory and visual modalities [1, 2]. During speech perception, auditory and visual information are merged into a unified percept, a mechanism called audio-visual integration (AV integration). As illustrated by the McGurk effect [3], this integration can occur even if the auditory and visual modalities provide incongruent information. For example, the simultaneous presentation of the visual velar /ka/ and auditory bilabial /pa/ leads normally hearing individuals to perceive the illusory *fusion* alveo-dental /ta/. The McGurk effect suggests that visual articulatory cues about place of articulation are integrated into the auditory percept, which is, thereby modified.

Deaf adults fitted with cochlear implant are able to integrate auditory and visual information: their performances are better in the AV modality compared to the auditory modality [4, 5, 6, 7]. Moreover, the visual modality seems to have a greater weight than the auditory modality for cochlear implanted deaf individuals, whereas it is the contrary for normally-hearing individuals [8, 9]. Indeed, the simulation provided to the auditory nerve by the cochlear implant is degraded with respect to place of articulation, voicing and nasality [10, 11, 12]. Therefore, the speech signal transmitted through the implant is incomplete and the need for lipreading is increased [13]. In case of incongruent auditory and visual information (McGurk stimuli), deaf implanted children and adults tend to report more responses based on visual information than hearing participants [14, 15, 8]. However, their reliance on visual information is flexible: Huyse, Berthommier & Leybaert [16] recently, showed that when incongruent AV stimuli are presented with degraded visually information, the proportion of audio responses increases. The audio-visual integration is thus an adaptive process in which the respective weights of each modality depend on the level of uncertainty of the auditory and visual signals.

Although informative, lipreading alone may only provide ambiguous information. Indeed, different phonemes (e.g. /b/, /p/ and /m/) share quite similar articulatory movements. For this reason, Cornett [17] proposed "Cued Speech" (CS) to help deaf people to perceive speech with the visual modality only. This system reduces the ambiguity related to speechread signal by making all the phonological contrasts of the oral language visible. Each syllable is uttered with a complementary gesture called the manual cue. Cued Speech was adapted to the French language in 1977, and is currently known as "Langue française Parlée Complétée" (LPC). In French CS, vowels are coded with five different hand placements near the face, and consonants are coded with eight handshapes (see Figure 1).

Figure1. *Cues in French Cued Speech: handshapes for consonants and hand placements for vowels (from Attina et al. [18]).*

Consonants and vowels sharing the same labial image are coded by different cues. The combination of visual information, provided by the articulatory lip movements and manual cues, allows deaf individuals to correctly perceive all syllables [19, 20]. Exposure to CS contributes to the elaboration of phonological representations, hence improving abilities notably

in rhyme judgments, rhyme generation, spelling production and reading [21, 22, 23, 24]. The advantages of exposure to CS are well-recognized. However, how the manual cues could impact the processing of AV integration is still to be studied.

Attina, Beautemps, Cathiard and Odisio [18] were the first to examine the temporal organisation of CS production of syllables, words and sentences. They found that manual cues anticipate lip gestures, with a maximum duration of 200 msec before the onset of corresponding acoustic signal. The same team also showed that deaf people use this anticipation of the manual cue over the lips during CS perception: they could extract phonological information when the cue was achieved and lip movement were not, hence reducing the number of potential syllables that could be uttered [25, 26, 27, 28]. These results reverse the classic way to consider the CS system: lip movement could disambiguate the information delivered by hand cues, instead of the reverse phenomenon.

Alegria & Lechat [29], and Leybaert, Bayard, Huyse & Colin [30] investigated integration of articulatory movement in CS perception. More precisely, they tried to determine the relative weight of phonological information delivered by lips movements and manual cue. They used an identification task of syllables without sound. Lip movements and manual cues were congruent (e.g. lip-reading /ko/ and handshape n°2, coding /v, z, k/) or incongruent (e.g lipreading /ko/ and handshape n°1, coding /d, p, ʒ/). Error analysis in the incongruent condition revealed that most of the time, participants perceived the syllables /do/ that was compatible with the manual cue (handshape n°1). Nevertheless, lip read information was also taken into account. Between the different consonants coded by the cue target, deaf participants choose less frequently those in contradiction with the lip read information (i.e. /po/ or / ʒo/). Besides, the visibility of information changed how lip read and manual information were taken into account: the weight of hand information increased with lips ambiguity. In both studies, results suggest an integrative process between lips and manual cue information.

The goal of the present research was to examine how manual cue information is integrated in audiovisual speech perception by deaf and hearing participants. Do CS receptors combine auditory, lips and manual information to produce a unitary percept? What is the weight of each kind of information in the final percept? How does auditory status affect it? To address these issues we designed the first experiment using audio-visual McGurk stimuli produced with manual cues. The manual cue was either congruent with auditory information, lip information or with the expected fusion. We wondered whether these experimental conditions would impact differently the pattern of responses of deaf and hearing subjects.

2. Method

2.1. Participants

Thirty seven adults participated in the study. They were split into three groups depending on their CS level and auditory status. One group consisted of eight deaf CS users (8 women; mean age: 18 years), hereafter CS-deaf. Three of them were implanted and five used binaural hearing aids. They were exposed to the CS from 2 - 3 years old for most of them, and from 14 years old for one of them. Another group consisted of fourteen hearing CS users (13 women and 1 men; mean age: 22 years), hereafter CS-hearing. Two of them had deaf close relation; others were students in speechtherapy and had CS training. The third group consisted of fifteen hearing non CS users (11 women and 4 men; mean age: 23 years), hereafter control hearing.

All participants were native French speakers with normal or corrected-to-normal vision and did not have any language or cognitive disorder. In order to assess CS knowledge level, a CS reception test was administered to all participants (TERMO, 2003).

2.2. Experimental material

2.2.1. Stimuli

A female French speaker was videotaped while uttering CV syllables consisting of one of the /p, k, t/ consonants articulated with /a/ (Figure 2).

2.2.2. Congruent conditions

Two unimodal and four congruent conditions were created.
- Audio only: /pa/, /ta/, /ka/ (each stimulus was presented 6 times)
- Lipreading only: /pa/, /ta/, /ka/ (3*6 stimuli)
- Audio with congruent manual cues (ref Figure 1): /pa/ and cue n°1, /ta/ and cue n°5, /ka/ and cue n°2 (3*6 stimuli)
- Lipreading with congruent manual cues (ref Figure 1): /pa/ and cue n°1, /ta/ and cue n°5, /ka/ and cue n°2 (3*6 stimuli)
- Lipreading with congruent audio : /pa/, /ta/, /ka/ (3*6 stimuli)
- Lipreading /pa/ with audio /pa/ and congruent manual cue n°1 (6 stimuli).

2.2.3. Incongruent conditions

Stimuli were also presented in incongruent conditions. Incongruent audio-visual syllables were created by carefully combining audio files /pa/ with non-corresponding video files /ka/ (with or without manual cue) and matching their onset. Four incongruent conditions were made which consisted of McGurk stimuli (audio/pa/ and lipreading /ka/) presented:
- without manual cue - Baseline condition (6 stimuli)
- with manual cue n°1, coding /p, d, ʒ / and congruent with auditory information /pa/ - Audio condition (6 stimuli)
- with manual cue n°2, coding /k, v, z/, and congruent with lip read information /ka/ - Lipreading condition (6 stimuli)
- with manual cue n°5, coding /m, t, f/ and congruent with the expected fusion /ta/ - Fusion condition (6 stimuli)

2.3. Procedure

The experiment took place in a quiet room. Video were displayed on a 17.3 inch monitor on a black background at eye level and at 70 cm from the participant's head. The audio track was presented at 65dB. On each trial, participants saw a speaker's video (during 1000 msec). Then, they were asked to repeat aloud the perceived syllable. Their answers were transcribed by the experimenter.

The experiment consisted of two blocks of 60 items. In each block all conditions were mixed. Before starting, participants saw five training items. The total duration of the experiment was approximately 30 minutes.

Figure 2. Stimulus sample. Video frame of condition lipreading with congruent cue (A), of condition audio only (B), of condition audio with congruent cue (C).

2.4. Results

2.4.1. Congruent conditions

As the groups were small (N ≤15), we used non parametric tests. As unimodal and congruent conditions are control conditions their results are summarized in Table 1.

Condition	CS-deaf, Mean (SD)	CS-hearing, Mean (SD)	Control hearing, Mean (SD)	Group effect *	p value
A /pa/	85(18.2)	100(0)	98(2.1)	Ns	/
A /ta/	62(21.9)	100(0)	100(0)	H>D	0.001
A /ka/	59(29.2)	100(0)	100(0)	H>D	0.002
A /pa/+cue1	93(12.5)	98(2.4)	95(7.1)	H>D	0.029
A /ta/+cue5	70(23.9)	98(0)	100(0)	H>D	0.000
A /ka/+cue2	93(9.4)	100(0)	100(0)	H>D	0.006
LR /pa/	68(18.8)	71(18.7)	91(10.7)	Ns	/
LR /ta/	52(27.1)	38(27.8)	46(24)	Ns	/
LR /ka/	22(14.6)	8(11.0)	14(13.5)	Ns	/
LR /pa/+cue1	100(0)	91(9.9)	77(17.8)	CS>Ct	0.021
LR /ta/+cue5	85(18.2)	69(36.9)	38(24.4)	CS>Ct	0.005
LR /ka/+cue2	89(15.6)	69(22.9)	52(24.9)	CS>Ct	0.021
A+LR /pa/	100(0)	100(0)	100(0)	Ns	/
A+ LR /ta/	64(27.1)	100(0)	100(0)	H>D	0.002
A+ LR /ka/	62(26.0)	100(0)	100(0)	H>D	0.002
A+LR+C /pa/	100(0)	100(0)	100(0)	Ns	/

Table 1. *Percentages of correct response in congruent conditions (A: Audio only ; A + cue : Audio with congruent manual cue ; LR : Lipreading only ; LR + cue : Lipreading with congruent manual cue ; A + LR : Audio with congruent lipreading; A+ LR + C : Audio with congruent lipreading and manual cue).*

2.4.2. Incongruent conditions

Participant's responses were classified in four categories: audio (when the response was /pa/), lipreading (when the response was /ka/), fusion (when the response was /ta/) and other responses. In the baseline condition, we used Mann-Whitney test to compare hearing (CS and non CS together) with deaf groups. In each group, the Wilcoxon test was used to compare response pattern between baseline condition and other experimental conditions.

• Baseline condition : Audio /pa/ + Lipreading /ka/

As illustrated in Table 2, deaf and hearing people had the same percentage of fusion response (p = 0.35) and auditory response (p = 0.12).

	Total hearing	CS-deaf	CS-hearing	Control hearing
Resp. audio /pa/	23(30.3)	8(14.6)	17(20.5)	27(28.9)
Resp. lipreading /ka/	1(4.3)	2 (3.6)	1 (2.4)	1 (2.1)
Resp. fusion /ta/	74(30.4)	81 (24)	78(20.7)	70(29.3)
Other response	2(5.2)	9(10.4)	2 (4.3)	2 (2.1)

Table 2. *Mean percentage of each kind of response (audio, lipreading, fusion and other) of all groups in Baseline condition. Standard deviations are indicated in brackets.*

• Audio condition : Audio /pa/ + Lipreading /ka/ + CS cue n°1 (p,d, ʒ)

Compared to the baseline condition, the addition of cue n°1 reduced the percentage of fusion response in CS-deaf group (p = 0.03) in favor of other responses congruent with cue information (60 % of other responses: 38% of /da/ and 19% of /ʒa/).
In CS-hearing group, the addition of cue n°1 reduced the percentage of fusion response (p = 0.001) and increased auditory response, from 17% to 60% (p =0.003).
In the Control hearing group, the addition of the cue had no effect on the response pattern.
Response patterns for each group in audio condition are shown in Table 3.

	CS-deaf	CS-hearing	Control hearing
Resp. audio /pa/	**18 (19.8)**	**60 (25)**	**37 (34.8)**
Resp. lipreading /ka/	2 (3.6)	0 (0)	1 (2.1)
Resp. fusion /ta/	20 (27.1)	21 (22.5)	57 (32.9)
Other response	60 (31.2)	18 (21.5)	5 (5.8)

Table 3. *Mean percentage of each kind of response (audio, lipreading, fusion and other) of all groups in Audio condition. Standard deviations are indicated in brackets.*

- Lipreading condition : Audio /pa/ + Lipreading /ka/ + CS cue n°2(k, v, z)

In the CS-deaf group, the addition of cue n°2 reduced the percentage of fusion response (p = 0.02) and increased the percentage of lipreading responses (p = 0.03), compared to the baseline condition. Besides, some participants gave the other response /za/ which is congruent with cue information.
In the CS-hearing group, the addition of cue n°2 also decreased fusion responses (p = 0.002) and increased lipreading responses (p =0.003).
In the Control hearing group, the addition of cue had no effect on the response pattern.
Response patterns for each group in lipreading condition are shown in Table 4.

	CS-deaf	CS-hearing	Control hearing
Resp. audio /pa/	2 (3.6)	20 (21.1)	35(33.4)
Resp. lipreading /ka/	**60 (32.8)**	**40 (27.4)**	**2 (3.9)**
Resp. fusion /ta/	25 (22.9)	33 (24.1)	61 (30.4)
Other response	13 (18.7)	6 (7.9)	2 (2.1)

Table 4. *Mean percentage of each kind of response (audio, lipreading, fusion and other) of all groups in Lipreading condition. Standard deviations are indicated in brackets.*

- Fusion condition : Audio /pa/ + Lipreading /ka/ + CS cue n°5 (m, t, f)

In all groups, the addition of cue not had effect on the response pattern (see Table 5). There was no increase of fusion responses compare to the baseline condition.

	CS-deaf	CS-hearing	Control hearing
Resp. audio /pa/	0 (0)	16 (23.7)	35 (33.8)
Resp. lipreading /ka/	0 (0)	0 (0)	1 (2.1)
Resp. fusion /ta/	**91 (10.4)**	**75 (28.6)**	**61 (31.1)**
Other response	9 (10.4)	9 (13.8)	3 (3.9)

Table 5. *Mean percentage of each kind of response (audio, lipreading, fusion and other) of all groups in Fusion condition. Standard deviations are indicated in brackets.*

3. Discussion

The goal of the present research was to examine how manual cue information is integrated in audiovisual speech perception. We wondered whether CS receivers can combine auditory, lips and manual information to produce a unitary percept. We expected that CS would differently modulate the respective weights of lip read and auditory information depending on auditory status.

Audiovisual speech integration in deaf
Our results showed that, as hearing people, deaf people with cochlear implant or binaural hearing aids can merge auditory and lipreading information into a unified percept. In Baseline condition (audio /pa/ + lipreading /ka/), percentages of fusion response were high and similar in hearing and deaf groups (respectively 84% and 81 %). Besides, contrary to previous studies, deaf people did not tend to report more response based on visual information than hearing participants [14, 15, 8]. One explanation might be that deaf and hearing people present comparable levels in auditory performance and lipreading. In unimodal conditions, percentages of identification for the auditory syllable /pa/ and for the lipreading syllable /ka/ did not differ between deaf and hearing group.

Cued Speech benefit
The present data confirmed previous results [19, 20].The addition of congruent cues to lip read information improved performance in CS perception for CS users (deaf and hearing). In CS-deaf group, the percentage of correct answer rose respectively from 47.3% in the Lipreading only condition to 91.3% in the Lipreading with manual cue condition, while it increased from 39% to 76.3% in the CS hearing group. CS is therefore an efficient system to help deaf people to perceive speech visually. Note that, for CS-deaf, the manual cue improved also perception with audio information. Indeed the percentage of corrects answers increase from 68.7% to 85.3% between Audio only condition and Audio with manual cue condition.

Manual cue effect on audio-visual speech integration fusion response)
In case of incongruent auditory and visual information (audio /pa/ and lipreading /ka/), the addition of manual cue not congruent with expected fusion response impacted the pattern of responses. For both CS deaf and hearing users, the proportion of fusion response decreased. The CS system can thus affect the audio-visual integration. In case of congruency between manual cue and expected fusion, the CS system support illusory perception. However, for all groups the percentage of fusion did not increase. One explanation might be that the proportion of fusion response in baseline condition was already fairly high in deaf and hearing groups (respectively 81% and 78%).

Weight of auditory, labial and manual information
While manual cue decreased fusion response in hearing and deaf CS users, the effect on other response depended on auditory status. Indeed, the addition of manual cues congruent with auditory information (but not with lip read information), only increased audio response /pa/ for CS-hearing but not for CS deaf group. In CS deaf group, the decrease of fusion response is in favor of other responses, congruent with the manual cue. Thus, despite their good performance in Audio only condition, CS-deaf seem more confident in visual information (such as lip read and manual cue). They cannot ignore lip read information, and rely more in this information than on the auditory one.
The addition of a manual cue congruent with lip-read information increased lipreading response for both group. These results suggest that deaf and hearing CS users can ignore auditory information when contradicted by lipreading and manual cue. CS system is not necessarily used with auditory information: therefore, not taking auditory information into account could be easier.

4. Conclusions

Implanted deaf people speech perception is based on the integration of auditory and labial cues. Deaf CS-users speech perception is based on the integration of labial and manual cues. Implanted CS-users deaf speech perception is based on the integration of auditory, labial and manual cues. Thus, speech perception in deaf people involves the same process as in hearing people: an integrative process of all cues provided by a same articulatory gesture. This integration occurs with "natural" information (such as lipreading or acoustic simulation of auditory system), with information stemming from technology (auditory simulation provided by cochlear implant), or from manual information created by humans (CS system). All those kinds of information are aimed at reducing information uncertainty: lipreading reduces uncertainty about auditory signal provided by cochlear implant, labial information reduces uncertainty about Cued Speech (or the reverse), and Cued Speech reduces uncertainty about audio-visual signal.

Multi-modal and multi-signal integration in speech perception is an adaptive process. The prevalence given to one auditory, lip read or manual information depends on auditory status.

Deaf people base their perception mainly on visual information (labial and manual cue). In case of incongruence between auditory, labial and manual information, they tend to perceive a unitary percept consisting of a compromise between all information. This compromise is not contradicted by lip read and manual cue information and it could ignore auditory information.

5. Acknowledgements

6. References

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