EFFECTS OF AUDITORY FEEDBACK ON HEARING-IMPAIRED SUBJECTS' PRODUCTION OF THE ROUNDING FEATURE: A PILOT STUDY

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ABSTRACT

This paper describes a pilot study that investigated the effects of auditory feedback on vowel production in prelingually hearing-impaired subjects. The rounding feature in French vowels is used to study the effects of hearing state on labial configurations and acoustic patterns. Subjects were recorded in two conditions: without their hearing aid (no auditory feedback) and with their hearing aid (with auditory feedback). The results show that temporary deprivation of auditory feedback causes changes in vowel production in the labial space. However, these changes are not reflected by a variation in vowel contrast, even though subjects tend to speak more clearly without their aid. It may be hypothesized that prelingually hearing-impaired subjects produce robust rounding features minimally influenced by temporary deprivation of auditory feedback.

Keywords: speech production; articulatory phonetics; hearing disorders.

1. INTRODUCTION

Auditory feedback is generally considered to be needed for acquiring speech. Recent acoustic studies on speech production show that when language acquisition is completed, a short-term deprivation of auditory feedback may cause changes in speech production [4, 5, 6, 7, 8]. Depending on the level of deprivation, speakers may or may not adopt a clearer speech strategy [7]. At the segmental level, a clearer speech strategy may be understood as vowel targets being less dispersed around the mean phoneme position and mean vowel targets being more distinct from each other [5]. In addition, intermediate vowels should be more sensitive to such auditory deprivation than point vowels [8].

When acoustic targets have already been defined, then, auditory feedback seems to be essential in maintaining the accuracy of corrective mechanisms [2]. Although many studies have been conducted on the role of auditory feedback in hearing-impaired subjects, very few articulatory studies have been carried out with hearing-impaired subjects.

In this paper, a pilot articulatory and acoustic experiment on vowels produced by congenitally hearing-impaired subjects with and without their hearing aid is described. The focus will be on the rounding feature, which is produced with a visible gesture. This feature is used in French, for instance, to oppose the unrounded vowels /i e/ to their rounded counterparts /y ø/.

2. METHOD

The corpus provided sequences representing the French oral vowels /i e y ø/, embedded in a carrier sentence *V comme pVpa* ('V as in pVpa'), where V is one of the above-mentioned vowels. Three adult subjects, two males (GT and ML) and one female (GH), produced the sequences. All three have a profound congenital binaural hearing loss (more than 90 dB), without any associated impairment. They are not cochlear implant users, but are aided (PTA range between 50 and 65 dB HL when wearing their aid(s)). Quebec French is their first oral language.

Recordings were made in a sound-attenuated room. The recording sessions were held in two parts. During the first part, the subjects were recorded without their hearing aids (WITHOUT condition); they were asked to remove the aids at least 15 minutes before the beginning of elicitation. Then, the corpus was elicited a second time, with the subjects wearing their hearing aids (WITH condition). In both conditions, participants were instructed not to speak louder than normal.

For each part of the session, the subjects read the sequences on a computer screen placed in front of them; sequences appeared 10 times each, in random order. Using a mirror set at a 45° angle beside the speaker's head, a single digital camera captured the speaker's face and profile view. In order to enhance the automatic extraction of lip configurations, blue make-up was applied to the speaker's lips. Lip area and lip protrusion were then measured, to create a lip area/lip protrusion two-dimensional labial space.

At the same time, the acoustic signal was captured with a high-quality microphone. Fundamental frequency and formant values (F1, F2 and F3) of the vowels produced were measured at the mid-point, before being transformed into mel units [1].

Those data provided a 2-D articulatory (labial) space (lip protrusion vs. lip area) and a 3-D acoustic space (M1 vs. M2 vs. M3). In each space, vowel dispersion (standard distance within each vowel category) and vowel contrast (Euclidean distance between mean vowel targets; here between /i/ and /y/ and between /e/ and /ø/) was calculated. Because of the small set of data used here, Wilcoxon rank-signed tests were carried out to compare subsets of results. Because of the small number of subjects, no gender comparison was carried out; the only independent variable taken into account here is hearing state.

3. RESULTS

3.1. Lip area and lip protrusion parameters

Sample labial spaces are presented in figure 1. A robust discriminant analysis was first carried out in order to verify that rounded/unrounded vowels could be segregated with labial parameters for all speakers. In each condition (WITH and WITHOUT), the two sets of vowels were discriminated at more than 90%, except for subject GH's lip protrusion parameter in the WITHOUT condition (54%) and the same parameter for speaker ML in both conditions (53% and 52%).

Previous acoustic studies show that postlingually deafened subjects produce vowels with a smaller average vowel spacing (AVS; [5]) when they lack auditory feedback. From an articulatory point of view, maybe lip area and lip protrusion values are less extreme when speakers do not wear their hearing aids. So, lip area values should be lower in the WITH condition than in the WITHOUT condition for rounded vowels. Furthermore, for those vowels, lip protrusion values should be higher in the WITH condition than in the WITHOUT condition.

For one of the three subjects (GH), lip area varied significantly between the two hearing states. Lip area values are significantly lower in the WITH condition, for rounded **and** unrounded vowels ($p < 0.001$). For the other two speakers, lip area values were not significantly different across conditions.

Unlike lip area, subjects GT and ML use the lip protrusion parameter differently across hearing states. However, whereas speaker ML produces significantly higher protrusion values in the WITH condition compared to the WITHOUT condition ($p < 0.001$), speaker GT significantly lowers this parameters ($p < 0.001$). This pattern is observed for both rounded and unrounded vowels.

To summarize, although at least one labial parameter varies significantly with hearing state for each speaker, they do not necessarily make the articulatory configurations more extreme in one condition. Moreover, there is interindividual variation in the direction of changes that occur across hearing states. In spite of this general shift of labial configurations, vowels may be more clustered within vowel categories and the opposition between rounded and unrounded vowels may be clearer in the WITH condition. Following [5, 6, 7], quantitative measures of these parameters were carried out.

3.2. Dispersion and contrast

Previous studies conducted with postlingually hearing-impaired subjects using cochlear implants show that vowel dispersion can be influenced by auditory feedback [5]. Moreover, vowel contrast – calculated here as the Euclidean distance between the mean positions of each pair of rounded and unrounded vowels – should be higher when subjects receive auditory feedback [5, 6]. It must be recalled, however, that the participants studied here are quite different from those used in previous studies (for instance, they are not cochlear implant users and they are prelingually deaf).

As shown in figure 2a, vowel dispersion tends to be higher in the WITH condition for one subject (GT) and did not vary for one subject (GH). So, temporary auditory feedback deprivation did not significantly influence the extent of the vowel target region in our subjects.

The contrast between rounded and unrounded vowels was also measured. The results shown in figure 3a are based on the /i/-/y/, /e/-/ø/ distances across hearing states. Although no statistical procedure could be applied, a lower vowel contrast in the WITH condition may be noticed, especially for subject GH.

A study of the acoustic space will help us find out whether these differences in the labial space influence the acoustic data.

3.3. Acoustic data

The results regarding the acoustic space are presented in figures 2b and 3b. As was found for the labial space, dispersion measures did not vary significantly across hearing states. As shown in figure 3b, there is a lot of variation between vowel contrasts; here again, a significant change in the vowel contrast values is observed for two out of three speakers, but not in the same direction. However, vowel contrast could be, once again, enhanced in the WITHOUT condition. It may be hypothesized that this speaker adopted a "clear speech" strategy in this condition [3, 7, 8].

4. DISCUSSION AND CONCLUSION

Table 1 shows a summary of each parameter studied, for each subject in the labial and acoustic space.

From an articulatory point of view, temporary deprivation of auditory feedback does cause changes in vowel production. In fact, significant changes were observed for at least one parameter in all speakers. However, the hypothesis that articulatory configurations would be more extreme, based on previous acoustic studies, was not confirmed.

Table 1: Directions of articulatory and acoustic changes in the WITH condition compared to the WITHOUT condition. * = significant differences

	labial				acoustic	
Sub.	area	protr.	disp.	contr.	disp.	contr.
GH	-*	+	-	-*	+	-*
GT	-	-*	+	-	+	-
ML	-	+*	+	-	-	+

Those configurations do not affect significantly vowel dispersion. In fact, for one of the three subjects, vowel dispersion was higher in the WITH condition, but not sufficiently so to allow us to conclude that a "clear speech" strategy was used [3, 7, 8]. This strategy may have been used by one subject, looking at the vowel contrast parameter. In fact, rounded and unrounded vowels are better separated in this condition, a strategy that is consistent across labial and acoustic spaces.

Two hypotheses can be put forward to explain these results. First, since the rounding gesture is a visible one, this opposition is robust enough to avoid auditory feedback regulation; Even though they change lip configuration in the protrusion and/or lip area space, those changes do not result in a decrease of contrast distances. Second, because all subjects were deaf from birth, their auditory targets may not be well defined, so the contrast is not improved even if they try to change their strategies. Further analysis on more subjects, on the whole vowel system and using tongue parameters will help answer this question.

5. ACKNOWLEDGMENTS

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Figure 1: Lip area and lip protrusion values for speaker GH, with and without auditory feedback.

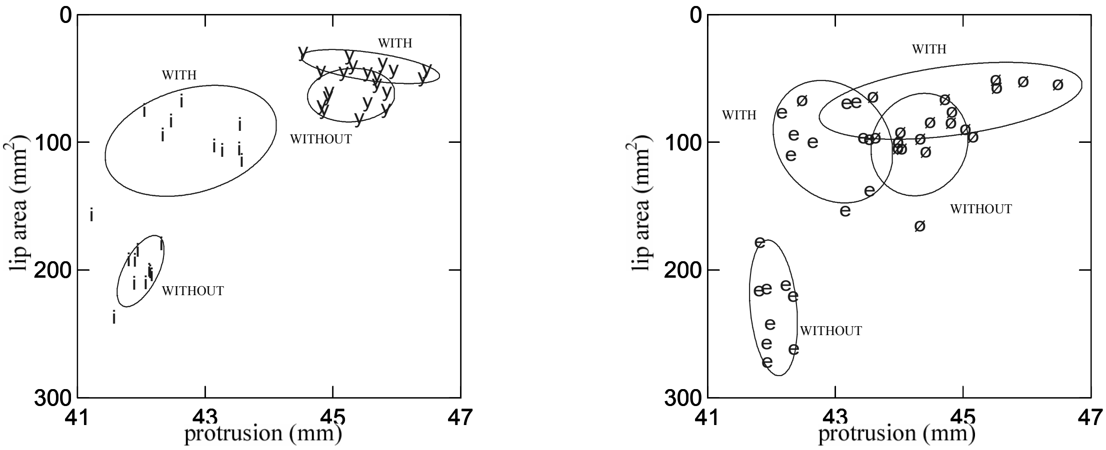

Figure 2: Vowel dispersion across hearing states for each subject. Error bars are one standard error of the mean.

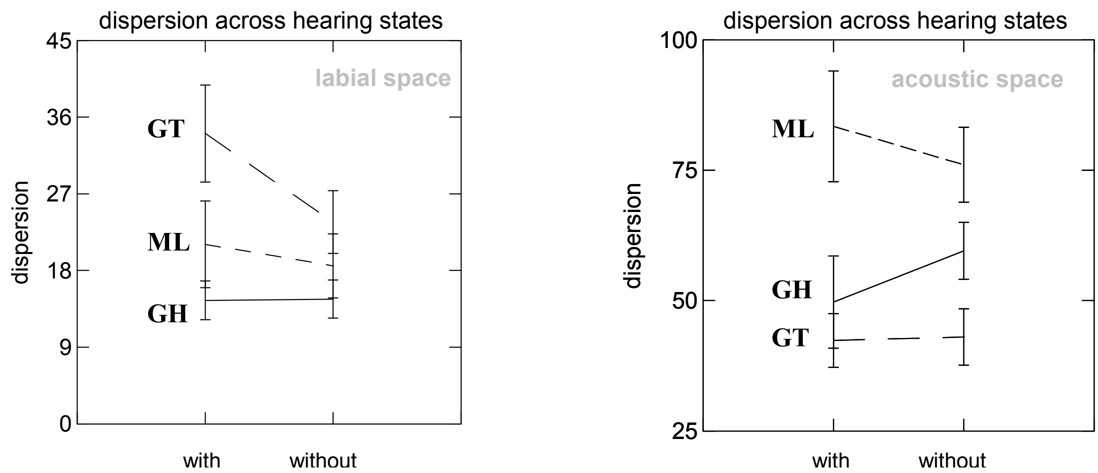

Figure 3: Vowel contrast across hearing states for each subject. Error bars are one standard error of the mean.