PHONETIC CONVERGENCE AND IMITATION OF SPEECH BY COCHLEAR IMPLANT PATIENTS

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ABSTRACT

Speech communication can be viewed as an interactive process involving a functional coupling between sensory and motor systems. One striking example comes from phonetic convergence, when speakers unconsciously tend to mimic their interlocutor's speech during communicative interaction. In order to test whether deaf people with cochlear implantation did recover such perceptuo-motor abilities, we measured online imitative changes on the fundamental frequency in relation to acoustic vowel targets in a non-interactive situation of communication during both unintentional and voluntary imitative production tasks. We showed that cochlear implanted participants have the ability to converge to an acoustic target, both intentionally and unintentionally, albeit with a lower degree than normal hearing participants. These results suggest that cochlear implanted patients recovered significant perceptuo-motor abilities less than two years following cochlear implantation.

Keywords: Phonetic convergence, imitation, cochlear implant, perceptuo motor linkage

1. INTRODUCTION

Conscious or unconscious imitation between two speakers in interaction is a quite widespread phenomenon in speech communication. The underlying perceptuo-motor mechanisms are considered to be a key mechanism in the evolution and development of human language (see a recent collection of papers on this topic in Nguyen et al., 2013 [1]). Surprisingly, while the recovery of speech perception and production abilities are largely studied in deaf or hearing impaired subjects equipped with a cochlear implant (CI), not much is known concerning their recovery of perceptuo-motor relationships. The present paper is focussed on this question, capitalizing on two recent studies by Sato et al. [2] and Garnier et al. [3] displaying both unintentional and voluntary imitative changes in relevant acoustic features of vowel targets during speech production in a non-interactive situation of communication. In these studies, participants were asked to produce different vowels according to an acoustic target based on their own f_0, with or without instruction to imitate the target. Results showed that participants strongly converged to the target not only in the imitative task, but also, at a lower degree, even if they are not asked to do so.

There are few studies on pitch control by deaf cochlear implanted participants. These studies often report higher f_0 values in CI participants than in normal hearing participants and more importantly, they reported that CI participants display more variations in F0 production than normal-hearing participants (e.g. [4]). However, Langereis [5] reported that while CI patients did not improve pitch production soon after the implantation, they seemed to reach similar to normative f_0 values one year post-implantation.

Concerning speech perception by CI patients, several factors appear to influence auditory performance. In Blamey et al. [6], 2251 CI patients participated to an auditory test, where they had to recognise phonemes, words and sentences. The experimenters reported that both duration of implant experience, age at onset of severe to profound hearing loss, age at cochlear implantation and duration of deafness influence speech perception to a certain extent – though inter-subject variability is quite large in this kind of study.

To our knowledge there are no studies on convergence and imitation ability in CI patients. So we attempt to replicate the results observed by Sato et al. [2] and Garnier et al. [3] on post-lingual deaf participants wearing a cochlear implant. The crucial question is to know whether CI patients display any convergence and imitation abilities at all, and if they do, to compare it quantitatively with the behaviour of normal hearing (NH) participants. An additional question concerns the role of participant's age, deafness duration and, duration of implant experience on convergence and imitation abilities.

2. METHOD

2.1. Participants

Two groups of participants performed the experiment. The first group consisted in fifteen normal-hearing participants (10 females and 5 males, mean age: 30 years old, range: 20-40) who had normal or corrected-to-normal vision and reported no history of speaking, hearing or motor disorders. The second group consisted in eight post-lingually deaf cochlear implanted participants (5 males, 3 females, mean age: 57 years old, range: 27-72)

Table 1 : Characteristics of participants with cochlear implants

Age (years)	Duration of deafness	CI experiment
65	58 y.	1 m.
56	35 y.	3 m.
66	25 y.	9 y.
60	1 m.	1 y. 4 m.
43	13 y.	2 m.
27	2 m.	2 y. 6 m.
67	2 m.	7 m.
72	30 y.	5 m.

2.2. Stimuli

A vowel database was created from /e/, /œ/, /o/ French vowels produced by one male and one female speaker. From these stimuli, f_0 was artificially shifted by steps of ±5Hz (from 80Hz to 180Hz for the male vowels, and from 150 to 350Hz for the female vowels) using the PSOLA module integrated in the Praat software (Boersma and Weenink, 2013).

2.3. Experimental procedure

The experiment was carried out in a sound-proof room. Participants sat in front of a computer monitor at a distance of approximately 50 cm. The acoustic stimuli were presented at a comfortable sound level through a loudspeaker, with the same sound level set for all participants. The Presentation software (Neurobehavioral Systems, Albany, CA) was used to control the stimulus presentation during all experiments. All participants' productions were recorded for off-line analyses.
The experiment consisted in three vowel production tasks. First participants had to individually produce /e/, /œ/ and /o/ vowels, according to a visual orthographic target. This allowed the experimenter to measure the participant's f_0. In the subsequent task ("convergence"), participants were asked to produce the three vowels according to an acoustic target. Importantly, no instruction to "repeat" or to "imitate" the acoustic targets was given to the participants. Finally, the third task ("imitation") was the same as the second task except that participants were explicitly asked to imitate the acoustic targets. The only indication given to participants was to imitate the voice characteristics of the perceived speaker. Acoustic target for each participant were 27 stimuli selected from the vowel database, with the 9 quantified f_0 frequencies varying from -20% to +20% by steps of 5% around his/her own pitch, as measured in the first task.
At the end of the experiment, participants were asked to perform a frequency discrimination test to estimate their pitch JND (JND: the threshold at whitch a change is perceived).

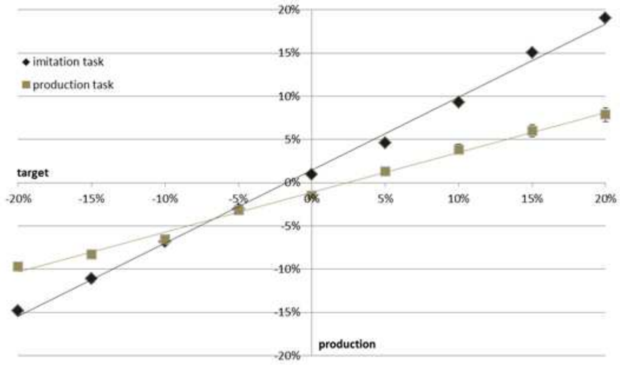
2.4. Data analysis

All acoustic analyses of participants' productions were performed using Praat. In the second and third tasks, we annotated the participant productions in order to estimate the percentage of errors in production compared to acoustic targets.
In all tasks, we measured f_0 for each correctly produced vowel. In the second and third tasks, linear regression between f_0 values for the target and participant utterances were estimated for each participant. Then, we analysed the slope of the linear regression and the value of correlation coefficients for each task and each participant. Finally, we estimated the correlation between slope values and age in each task for the two groups of participants, and the correlation between slope values and duration of deafness or duration of implant experience for CI users.

3. RESULTS

3.1. NH participants

Figure 1 : Phonetic convergence and voluntary imitative changes observed in normal hearing participants



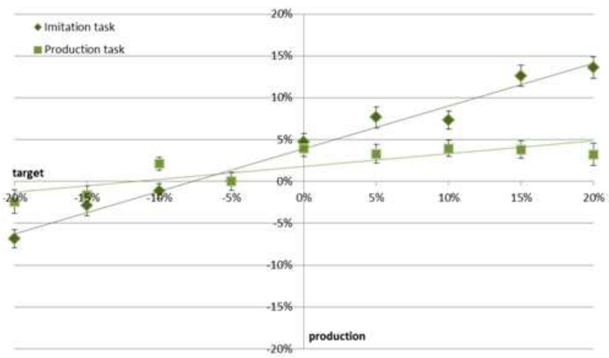
For NH participants, imitative changes were observed in both tasks, though stronger in voluntary imitation. Slope coefficients differed significantly from zero in both the production ($t(14)=5.98$; $p<0.001$) and imitation ($t(14)=35.78$; $p<0.001$) tasks. In addition, slope coefficients were higher in the imitation compared to the production tasks (on average: 0.87 vs. 0.45; $t(14)=6.02$; $p<.001$). Similarly, correlation coefficients differed significantly from zero in both the production ($t(14)=8.3$; $p<0.001$) and imitation ($t(14)=93.34$; $p<0.001$) tasks, and were higher in the imitation compared to the production tasks (on average: 0.94 vs. 0.64; $t(14)=4.3$; $p<0.001$).

Normal-hearing participants made no errors in both tasks.

Finally, there was no correlation between “convergence” and “imitation” ($r^2=0.12$). There was no correlation either between “convergence” and participants age ($r^2=0.00$), “imitation” and participant's age ($r^2=0.00$), not between convergence or imitation tasks and JND values (convergence: $r^2=0.00$, imitation: $r^2=0.00$).

3.2. CI participants

Figure 2: Phonetic convergence and voluntary imitative changes observed in cochlear implanted participants



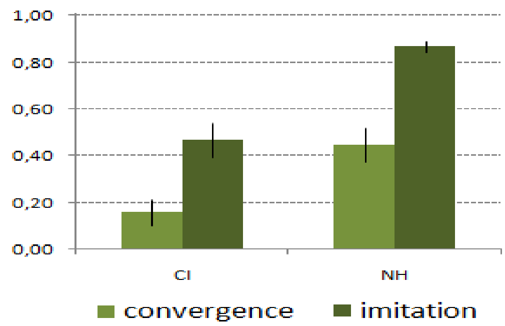
As for NH participants, for CI participants, imitative changes also appeared in both tasks. Slope coefficients differed significantly from zero in both the convergence ($t(7)=2.82$; $p<0.05$) and imitation ($t(7)=6.07$); $p<0.001$) tasks. In addition, slope coefficients were higher in the imitation compared to the convergence tasks (on average: 0.46 vs. 0.15; $t(7)=5$; $p<0.005$). Similarly, correlation coefficients differed significantly from zero in both the convergence ($t(7)=3.4$; $p<0.05$) and imitation ($t(7)=6,84$; $p<0.001$) tasks, and were higher in the imitation compared to the convergence tasks (on average: 0.58 vs. 0.25; $t(7)=4.61$; $p<0.01$).

Cochlear implanted participants made a number of errors in both tasks, with similar of error percentage in the convergence (15%) and imitation tasks (12%).

For this group, there was no significant correlation between convergence and imitative task ($r^2=0.37$). There was also no correlation between the others factors, which were age of deafness, deafness duration or duration of implant experiment, neither with convergence slope nor with imitation slope (all $r^2 < 0.3$. Finally, as for NH participants, correlation between JNDs and convergence or imitation performance was not significant (convergence task: $r^2=0.04$, imitation task: $r^2=0.03$).

Comparison between normal-hearing and cochlear implanted participants

Figure 3: Phonetic convergence and voluntary imitative slope changes between normal hearing and cochlear implanted participants



In the convergence task, slope coefficients was significantly higher for NH (than for CI participants (on average: 0.45 vs. 0.15; $t(22)=2.6$; $p<0.05$). The same happened in the imitation task (on average: 0.87 vs. 0.46; $t(22)=6.23$; $p<0.00$).

Variability, as measured by SEM, in convergence was higher in imitation (0.09) than in convergence (0.06) for CI, whereas it was the inverse for NH (imitation: 0.02; vs. convergence: 0.07).

As previously noted, the percentage of errors was of course higher for CI participants (12% to 15%) than for NH subjects who produced no error in both tasks.

4. DISCUSSION

To summarize, we firstly reduplicate the previous findings by Sato et al. [2] and Garnier et al. [3] for NH participants. Indeed, we found imitative changes towards the acoustic target in both tasks, with stronger convergence in imitation than in convergence. Furthermore, we found no correlation between the two tasks.

For the CI participants, we found that they can imitate and converge towards an acoustic target. This is a novel result that appears of importance, showing that cochlear implanted subjects are able to estimate the pitch of a target voice and monitor their own vocal source to attempt to get closer to this target. Even more strikingly, they do it even in a "convergence" paradigm where no explicit imitation instruction is provided to the subjects. This shows that CI subjects in our experiment have already recovered a good ability to associate auditory with motor parameters. This should be crucial for the retuning of their speech production system (see Perkell et al., 1992), enabling them to improve their internal model (Perkell et al., 2000). Interestingly, recovering perceptuo-motor abilities could also be of importance for their speech perception abilities, considering the proposals about the role of the motor system in speech perception (e.g. [7-8]). However, there is one difference between the two groups. Indeed, convergence/imitation is smaller and more variable in CI subjects compared with NH ones.

Importantly, contrary to Blamey et al. (2012) who showed that deafness duration and age at deafness onset are two factors that influence speech perception performance, we do not find any correlation between those factors and CI abilities to imitate or to converge towards an acoustic target, but it is possible that this correlation absence may be caused by our limited sample of participants.

Finally, contrary to NH participants, CI participant's responses are not always correct, which means that isolated vowel perception is difficult for them. Actually, it is known that CI listeners need formant transition to accurately categorize a vowel, as shown by [7].

To conclude, we showed here, for the first time, that cochlear implanted participants have the ability to converge to an acoustic target, intentionally and unintentionally. Therefore, they recover significant perceptuo-motor abilities, which could be crucial for improving both speech production and perception ability, with several factors influencing this recovery, like the age of deafness onset, the deafness duration and the duration of CI experience.

5. ACKNOWLEDGEMENTS

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