Nasal vowel production and grammatical processing in French-speaking children with cochlear implants and normal-hearing peers.

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Abstract

Our study investigates morphemic receptive skills, quality of phonological representations, and production abilities of the acoustic nasal feature in French, a language with nasal vocalic phonemes. We examine these skills in two groups: children with cochlear implants (CI group) and their normal hearing peers (NH group). The results reveal weaker receptive skills and more phonological errors in production among the CI group. Additionally, the CI group shows a specific use of different acoustic cues associated with vowel nasality, suggesting a perceptual-productive profile that focuses more on perceptually salient cues. This profile may be related to language skills, as the use of subtle acoustic cues is associated with better morphemic processing skills.

Index Terms: speech production, vowel nasality, cochlear implant, language development

1. Introduction

1.1. Language and cochlear implant

Cochlear implant is now widely used in young children and adults with sensory hearing loss. The improvement of auditory perception and intelligibility in young children with pre-lingual deafness is well documented. However, studies on the language development of children with implants show a large variability in language perception and production skills, as well as certain linguistic components that appear to have delayed and/or atypical developmental profiles compared to children with normal hearing. Specifically, in phonological skills, some studies have shown differential deficits depending on the phonological features, impacting categorical perception [1] and production abilities [2]. The morphosyntactic component is often reported to be deficient in groups of implanted children compared to their normal hearing peers [3, 4]. These different findings lead us to believe that the cochlear implant, although allowing access to sufficient language input to acquire many phonological contrasts, may not be sufficient in the processing of all acoustic features, especially in less salient perceptual contexts, such as the processing of grammatical morphemes. This phenomenon could be explained, on the one hand, by the limited number of electrodes allowing to code the speech sound, much lower than the number of hair cells coding the same information in a healthy ear, and, on the other hand, by the various transformations of the acoustic signal operated by the device. Some speech sounds could be more affected by the processing of the sound by the cochlear implant, in particular those whose oppositions are based on complex acoustic cues and marked by a precise spectral processing, which is the case of the nasal vowel feature. However, most of the studies conducted in the field have been developed in the context of languages whose phonological system is free of nasal vowels, which could have largely obscured the phenomenon.

1.2. Vocalic nasality and cochlear implant

Nasal vowels are complex acoustic realizations, by the coupling of two resonance systems via the lowering of the soft palate within the vocal tract. The coupling of the oral cavities with the nasal cavities results in numerous transformations of the acoustic signal. Styler [5] notes four types of acoustic changes related to nasality: the appearance of nasal poles, the appearance of zero (or "anti-formant) poles, changes in formant structures, and diffuse spectral changes. Another way of looking at nasal vowels acoustically is to consider that its perception/production relies on two types of cues: those related to the oral configuration specific to any vowel, and those related to the coupling of the oro- and naso-phrayngeal cavities through the lowering of the soft palate [6]. The phonetic distinction between oral and nasalized vowels is thus carried by fine and subtle variations in the acoustic signal. If, as suspected, the signal processing by the cochlear implant does not encode spectral information as finely as the healthy ear, nasalized vowels may be less well perceived/produced in implanted populations. Borel [7] found difficulties in nasal vowel perception in a study conducted on 82 French-speaking implanted adults. The subjects in the study showed a tendency to perceive nasal vowels as oral vowels closed on their oral configuration. In a previous study, we investigated the perceptual and production abilities of children aged 4 to 12 years with cochlear implants in comparison to their normal hearing peers [8]. The results showed slight difficulties in discrimination and identification of nasal vowels within the children with cochlear implants. Acoustic analyses performed on the productions showed proximity effects between nasal vowels and the oral vowel close on their F1 and F2 values. The nasal vowels were produced with lower bandwidth values and longer segmental durations, suggesting a productive profile more focused on the more salient perceptual cues (oral configuration, segmental durations) assumed to be better encoded by the cochlear implant. These data therefore suggested a link between this production profile and the way in which cochlear implanted children perceive and exploit the different acoustic cues through their implant. Based on this literature, we wanted to investigate the phonetic production abilities of nasal vowels in young children with normal hearing and cochlear implants, as well as the impact of these production abilities on morpheme processing. Indeed, there is reason to suspect an effect of the difficulties in the perception of acoustic features, including the nasal feature, on the quality of phonological representations, a complete and qualitative phonological system being necessary for the adequate processing and production of lexical and grammatical morphemes.

2. Method

The study involved the administration of two tasks to two groups of children (cochlear implanted and normal hearing) with the objective of studying, on the one hand, grammatical and lexical morpheme processing skills, and on the other hand, phonological structuration, and the ability to phonetically mark vowel nasality, as well as the link between these different skills.

2.1. Participants

The study was conducted on two groups of French-speaking children: 27 children with normal hearing (NH group) and 16 children with cochlear implants (CI group). The children in the CI group were 8 boys and 8 girls aged between 4 years 6 months and 7 years 3 months, with an average age of 5 years 7 months (standard deviation: 1 year 3 months). They all had bilateral profound prelingual deafness and received an oralist education. Most subjects (15) benefitted bilateral implantation. The whole sample received the (first) implant between 7 months and 3 years 3 months.

2.2. Tasks

Participants completed a comprehension task and a picture naming task. The comprehension task consisted of presenting a word/sentence to the child and ask him/her to point to the corresponding picture out of two. The task had a total of 28 items. The differences between the target words/sentences and their distractors involved 13 number marks [(e.g. “il va” - /il va/ (he goes) / “ils vont” - /il vɔ̃/ (they go)], 7 gender marks [(e.g; “boulanger” - /bulɑ̃ge/ (baker – male gender) – “boulangère” - /bulɑ̃gɛʁ/ (baker – female gender)] and 8 sound variations between minimal pairs [“bain” - /bɛ̃/ (bath) / “banc” - /bɑ̃/ (bench)]. These different grammatical and lexical markings were supported by different phonological oppositions: oral/nasal, oral/oral or nasal/nasal vowel substitutions and phonemic additions. The target items were presented through an audio recording. The picture naming task, which aims to study children's phonological and phonetic production, developed by Philippart De Foy et al. [9], consists of naming 48 items including all the phonemes of the French in different positions (initial, medial, final).

2.3. Data treatment and statistical analysis

For the comprehension task, the total score and the various associated subscores (number marks, gender marks, lexical items) were transformed into a d' score, calculated according to the method of MacMillan & Creelman [10] for a two-alternative forced choice. Raw subscores by type of phonological transformation carrying the grammatical/lexical opposition were also calculated: subscores for items opposed by oral/nasal vowels, oral/oral vowels and nasal/nasal vowels. For the naming task, children's productions were transcribed using Phon software [11] and then analyzed from phonological and phonetic perspectives. Phonological analyses consisted of calculating the percentages of correct consonants and vowels. Analyses of the errors produced were also carried out with our two groups based on the transcribed productions. The phonetic analyses consisted in the analysis of the distinction between oral and nasal vowels, by comparing each nasal with its phonological and phonetic correspondent. We therefore compared so-called phonological (following the classical articulatory description: /ɑ̃/-/a/; /ɔ̃/-/ɔ/; /ɛ̃/-/ɛ/) and phonetic (/ɑ̃/-/ɔ/; /ɔ̃/-/o/; /ɛ̃/-/a/) pairs. These comparisons by phonetic proximity are inspired by the results obtained by Borel [7]. The distinction between each oral and nasal vowel was based on two types of acoustic cues: the values of Euclidean distances (E.D.) in an F1/F2 space and the A1-P0 values. A1-P0 accounts for the increase in amplitude of P0 (first nasal pole) in conjunction with the decrease in amplitude of the first harmonic (A1), and is a reliable cue to nasality [5, 12, 13]. We used the correction proposed by Chen [12] to control the phonetic context and the vowel type, so we used the A1-P0 compensated values. The formantic pattern and A1-P0 compensated values were obtained using an automatic procedure of acoustical cues extraction with a PRAAT [14] script adapted from Styler [5]. These two specific acoustic cues were selected because they carry some distinct articulatory correlates of nasality features: while the F1/F2 Euclidean distance (E.D.) values reflect the oral configuration of the productions, the A1-P0 values reflect cues of articulatory mechanisms based on fine acoustic processing (velopharyngeal coupling – VP-coupling). It is assumed that the oral configuration types of cues, which are more salient because they are less dependent on fine acoustic perception abilities, are more supportive for the nasal perception mode in the implanted children. Given the small sample size, non-parametric tests were conducted for the analysis of the linguistic data. Acoustic cues were studied by comparing the differences between each nasal-oral pair (phonological/phonetic pairs) in our two groups and were analysed using MANOVA. Correlations were also performed applying the Bravais-Pearson correlation coefficient to the mean values of acoustic cues by pair types and sentence comprehension scores, but also for the different scores by chronological/auditory age of the subjects[1].

[1] Distinction between chronological and auditory ages is commonly use in research including cochlear implant children. Auditory age is obtained by subtracting the chronological age from the age at implantation.

3. Results

3.1. Receptive skills

The comprehension task score shows a lower performance in the CI group compared to the NH group. Differences are found in the total score and in the subscores for the items dealing with grammatical number and gender marks, and for the lexical items (table 1).

Table 1: *Scores on the sentence comprehension task.*

Score types	NH group	CI group	Mann-Whitney
Total score	0,75 (0,11)	0,59 (0,09)	-3,82 ; p < .001**
Number marks	0,67 (0,13)	0,55 (0,15)	-2,34 ; p = .019*
Gender marks	0,78 (0,13)	0,61 (0,18)	-2,552 ; p = .011*
Minimal pairs	0,86 (0,14)	0,66 (0,10)	-4,056 ; p < .001**
Oral-nasal opposition	83,70 (13,05)	56,88 (12,50)	-4,596; p < .001**
Oral-oral opposition	62,96 (21,35)	52,08 (29,74)	-1,442 ; p = .149
Nasal-nasal opposition	77,78 (18,49)	68,75 (19,12)	-1,476 ; p =.140

Looking at the types of phonological processes carrying the grammatical/lexical marks of the items, we see that children in the CI group have lower scores for items where the opposition was carried by a distinction between an oral and nasal vowel. We also studied the effect of chronological and auditory age using correlations: while children in the NH group have their chronological age positively correlated with their scores on the total score and the "number marks", "minimal pairs", and "oral-nasal oppositions" items, we only find in the CI group a positive correlation between their auditory age (not chronological) and the "oral-nasal oppositions" subscore.

3.2. Productive skills

Analyses of the phonological structure of the productions obtained in the naming task showed lower scores in our CI group children in terms of percentages of correct consonants (NH= 89.43; CI = 65.12; U(43) = -4.699; p <. 001**), correct vowels (NH = 95.38; CI = 79.0734; U(43) = -4.749; p <.001**), and to the total correct phoneme score (NH = 91.92; CI = 70.7387; U(43) = -4.849; p <.001**). The study of the types of errors produced shows that children in the CI group commit significantly more consonantal deletions and phonemic substitutions. The substitutions made were mainly denasalizations of nasal consonants (NH: 0.44; CI: 2.31) and nasal vowels (NH: 0.77; CI: 5.69) in the CI group, but also nasalization of oral consonants (NH: 1.04; CI: 6.44). Correlations between these scores and the subjects' characteristics show that an increase in the chronological age of children in the NH group is positively associated with higher percentages of correct consonants and vowels, as well as a decrease in the number of denasalizations of nasal vowels. For children in the CI group, an increase in auditory age (but not chronological age) was associated with a higher percentage of correct consonants and a decrease in the number of denasalizations of nasal consonants.

The acoustical analyses on the nasal/oral pairs showed group effect for the Euclidean distances of F1/F2 in favor of the CI group (NH = 695 Hz; CI = 755 Hz; F(1) = 51.178 ; p<.001), a pair type effect in favor of the phonological pair (Phonological = 825 Hz; Phonetic = 603 Hz; F(1) = 583.096; p<. 001) and an interaction effect (F(1,12500) = 22.446; p<. 001), the NH group showing greater differences for the phonetic pairs than the CI group (Figure 1).

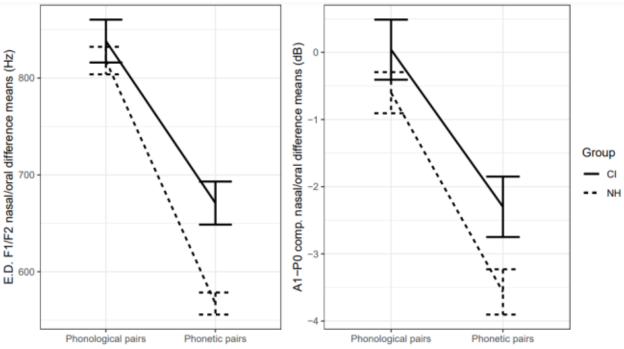

Figure 1: *Euclidian distances on F1/F2 (left) and A1-P0 differences (right) of the phonological and phonetic pairs in the CI (solid line) and NH group (dashed line).*

It should be noted that lower A1-P0 compensated values is correlated with higher nasality. The A1-P0 compensated values also show a group effect, the NH group showing lower A1-P0 values and thus greater nasality (NH = -2.05 dB; CI = -1.12 dB, F(1) = 23,14 ; p>.001) and a pair type effect (Phonological = -0,38 dB; Phonetic = - 3.12 dB; F(1) = 178.938 ; p <.001) the lower values being associated with the phonetic pairs. No interaction between these two variables F(1,12500) = 2.497 ; p=.114) were shown, the NH values being greater for the two types of pairs. While an increase in chronological age is associated with a higher marking of the oral/nasal distinction using nasal resonance (A1-P0 values) in the NH group, the increase in auditory age of children in the CI group is instead associated with this marking through oral configuration (Euclidean distances of F1/F2).

3.3. Receptive and productive skills

Correlation studies show that the increasing marking of nasality throughout formantic pattern acoustical cues (E.D. F1/F2 values) within the phonological pairs is negatively correlated with the subscore “oral/nasal opposition items” of the comprehension task only in the CI group (r = -0.586, p=.022) (figure 2).

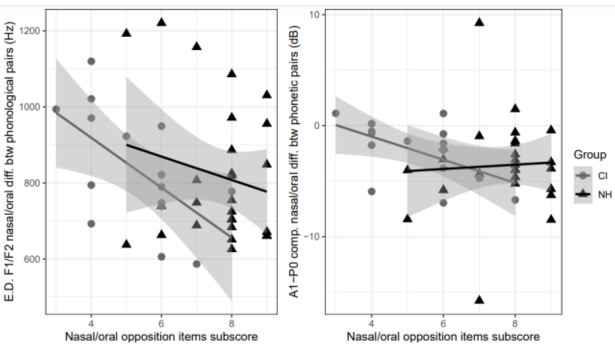

Figure 2: *Scatter plot and regression lines between nasal/oral opposition subscores and Euclidian distances on F1/F2 for phonological pairs (left) and A1-P0 differences for phonetic pairs (right) in CI (dots – grey line) and NH group (triangles – black line).*

Conversely, increasing marking of the nasality throughout the use of VP-coupling acoustic cues (with a lowering of the A1-P0 compensated values) of the phonetic pairs was associated with greater "oral/nasal opposition items subscores" in the CI group (r = -0.537, p=.039).

4. Discussion

Our results show weaker linguistic skills in our group of implanted children and a productive profile in terms of specific vowel nasality which could partially explain the linguistic difficulties. Regarding the results of the comprehension task, we observe lower scores in the CI group on the different types of grammatical marks targeted. These difficulties could be related to phonological processing difficulties, with grammatical marks carried by oral/nasal distinctions being the most affected. These phonological processing difficulties can be linked to the phonological production skills found in the naming task, children in the CI group having lower percentages of correct consonants and vowels than their hearing peers, and the most frequent substitutions made on vowels are nasal vowel oralizations.

Our acoustic analyses allow us to make different hypotheses about how these nasal vowels could be perceived by our CI group. Indeed, our results suggest that the productions of the children in the CI group have less nasal/oral distinctions carried by VP-coupling acoustic cues than NH group. Conversely, the CI group showed greater nasal/oral distinctions in the formantic pattern acoustic cues. These results are similar to those from a previous study [8] and suggest that the VP-coupling acoustic cues are coded with less accuracy than the formantic pattern acoustic cues by the cochlear implant. Formantic pattern acoustic cues is supported by frequency coding: we can suppose that this kind of acoustic information is well coded by the CI. Moreover, this information is the perceptual correlate of the oropharyngeal articulatory pattern, that can be, at least for some vowel characteristics (anteriority, roundness), visually accessible. In contrast, VP-coupling acoustic cues are supported by more subtle spectral information (harmonic intensity gradient, bandwidth of formant), and isn't visually accessible. This visual effect on production have also been reported in Grandon [2], CI children showing differences with NH children only for the less visually accessible vowel and consonant segments (medial and posterior segments).

Moreover, the acoustic analysis has shown different strategies for the distinction of the types of nasal/oral pairs. Although nasal/oral phonological pairs are differentiated by both a distinct formant pattern and VP-coupling, V-P coupling seems to be the more salient cue for distinguishing between nasal and oral phonetic pairs. This could explain why the nasal/oral phonetic pairs are more complex to distinguish for the CI users and thus the error pattern retrieved in our results and in previous studies [7]. Moreover, we note links between acoustic data and morphemic processing in the CI group: best performances in nasal/oral opposed items process are associated with greater VP-coupling nasality marking, but fewer nasality marking with the formantic pattern. These latter findings may explain the importance of using fine acoustic cues in the phonological structuration and for processing grammatical and lexical morphemes carried by nasal/oral vowel distinction for CI children.

Finally, it should be noted that age effects are observed on different aspects in our two groups. Indeed, older NH children perform better on the different lexical and grammatical gender marks, as well as on oral/nasal distinctions, and exhibit better phonological production on all types of segments. On their side, CI children show improvement in their processing abilities related to their auditory age only in the processing of oral/nasal distinctions and have an increased level of phonological production for consonants but not vowels. These differences in age-related development are also reflected in the types of cues used for the acoustic marking of nasality: NH children show an increase in VP-coupling cues with age, while CI children exhibit changes in cues related to articulatory configuration. One could see a link between this evolution of a perceptual profile more focused on visually salient cues and the positive evolution in consonant production: older CI children may devote more perceptual and productive attention to more perceptually salient acoustic cues, which are also relevant for the perception/production of consonantal segments.

However, this study has several limitations. Indeed, the variability of performance in groups of implanted children has been widely documented, so it would be necessary to enlarge the sample of children tested. In addition, there are a multitude of other acoustic cues that reflect vowel nasality: the study of various other cues would possibly provide a better account of the perceptual-productive profile of the children tested.

5. Conclusions

This study suggests, congruently with the literature, that the population of implanted children is more likely to present linguistic difficulties, particularly in the phonological and morphosyntactic components. Investigation of the phonetic production profiles of the vowel nasal feature suggests a possible perceptual saliency effect of acoustic cues assumed to be better encoded by the implant (configuration of the articulators), to the detriment of more subtle acoustic cues. This perceptual strategy seems to be effective in producing a majority of correct productions, but could lead to inaccuracies in the constitution of the phonological system, and thus in the processing of grammatical and lexical morphemes. Early and adequate assessment and management of the utilization of acoustic cues present in the sound signal seems to be of the greatest interest for this population.

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7. References

[1] S. Bouton, W. Serniclaes, J. Bertoncini, and P. Colé, "Perception of speech features by French-speaking children with cochlear implants". *Journal of Speech, Language, and Hearing Research*, vol. 55, pp. 139–153, Feb. 2012.

[2] B. Grandon, "Développement typique et atypique de la production de parole : caractéristiques segmentales et intelligibilité de la parole d'enfants porteurs d'un implant cochléaire et d'enfants normo-entendants de 5 à 11 ans. [Doctoral dissertation, Université Grenoble Alpes], Dec. 2016.

[3] B. Bourdin, L. Ibernon, B. Le Driant, C. Levrez, and L. Vandromme, “Troubles morphosyntaxiques chez l’enfant sourd et chez l’enfant dysphasique : similarités et spécificités” Revue de neuropsychologie, vol. 8, no. 3, pp. 161-172, 2016.

[4] L. Duchesne, A. Sutton, F. Bergeron and N. Trudeau, “Le développement lexical précoce des enfants porteurs d’un implant cochléaire. Early Lexical Development of Children with Cochlear Implants”. *Revue canadienne d’orthophonie et d’audiologie*, vol.34, no.2, pp. 132-145, Jun. 2010.

[5] W. Styler, “On the acoustical features of vowel nasality in English and French”, *The Journal of the Acoustical Society of America*, vol. 142, no. 4, pp. 2469-2482, Oct. 2017.

[6] V. Delvaux, “Les voyelles nasales du français : Aérodynamique, articulation, acoustique et perception”. GRAMM-R : études de linguistique française, Bruxelles : Peter Lang, Dec. 2012

[7] S. Borel, “Perception auditive, visuelle et audiovisuelle des voyelles nasales par les adultes devenus sourds. Lecture labiale, implant cochléaire, implant du tronc cérébral”. [Doctoral dissertation : Université Sorbonne Paris Cité], 2015.

[8] S. Fagniart, B. Charlier, V. Delvaux, A. Huberlant., K. Huet, M. Piccaluga, I. Watterman and B. Harmegnies, “Perception et production du trait de nasalité vocalique chez l’enfant porteur d’implants cochléaires”. *XXXIIIe Journées d'Études sur la Parole*, pp. 217-225, Jun. 2020

[9] M.P. De Foy, V. Delvaux, V., K. Huet, M. Monnier, M. Piccaluga and B. Harmegnies, “Un protocole de recueil de productions orales chez l'enfant préscolaire: une étude préliminaire auprès d'enfants bilingues”. *XXXIIe Journées d’Études sur la Parole*, pp. 639-647, Jun. 2018

[10] G. McMillan and C.D. Creelman, “Detection theory: A user’s guide”, 1991

[11] G. Hedlund and Y. Rose, Phon 3.1 [Computer Software], Retrieved from https://phon.ca.

[12] M. Y. Chen, “Acoustic correlates of English and French nasalized vowels”, *The Journal of the Acoustical Society of America*, vol. 102, no. 4, pp. 2360-2370, Oct. 1997

[13] C. Carignan. “A practical method of estimating the time-varying degree of vowel nasalization from acoustic features”, *The Journal of the Acoustical Society of America*, vol. 149, no. 2, pp. 911-922, Feb. 2021

[14] P. Boersma and D. Weenink, D. Praat: doing phonetics by computer [Computer program]. Version 6.2.06, Jan. 2022 from https://www.praat.org.