

Vibrant coda acquisition: the establishment of acoustic-phonetic cues

Aquisição da coda vibrante: o estabelecimento de pistas fonético-acústicas

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ABSTRACT

Purpose: To acoustically characterize the target productions of vibrant coda; to identify the presence (or not) of covert contrasts in productions omitting the vibrant coda; and to characterize how these contrasts are acoustically marked in speech. **Methods:** Recordings of words produced by 30 children (3-4 years old) with typical language development were selected from a database using the software PRAAT. The words analyzed involved the production of the medial vibrant coda in stressed position, in the context of vowels /i/, /a/, and /u/. After auditory-perceptual characterization of the productions, an acoustic analysis was conducted considering the formant trajectory (F1, F2 and F3) and the relative length of the syllable containing the vibrant coda. Data were statistically analyzed. **Results:** In the auditory-perceptual analysis, 77.8% of the productions were identified as the target vibrant coda, 12.2% were omitted, and 10% were substituted, varying according to the vowel context. In the acoustic analysis of target productions, it was verified that children preferably used acoustic parameters related to the formant trajectory of F2 and F3 to mark the acquisition of this structure. Analogously, in the acoustic analysis of omitted productions, it was identified the presence of covert contrasts, marked by the interception of the adopted acoustic parameters. **Conclusion:** Acoustic analysis seems to be a necessary and indispensable resource for describing and characterizing how children start mastering acoustic-phonetic cues, until they reach the effective contrast of the vibrant coda.

Keywords: Speech acoustics; Child; Child language; Phonetics; Speech production measurement

INTRODUCTION

From the phonological point of view, the syllable is a unit with constituents hierarchically organized, as to know: an attack and a rhyme, which, in turn, may be ramified into nucleus and coda⁽¹⁾. For each syllabic constituent there is a specific standardization of which and how many segments may occur in each position. In the case of Brazilian Portuguese (BP), the coda position may be filled by the consonants vibrant /R/, lateral /L/, fricative /S/ and nasal /N/⁽²⁾.

The acquisition of vibrant coda, particularly, has been una-

nimously pointed as having a complex and late mastering by the children⁽³⁻⁸⁾. This complex and late mastering is explained both by its complex syllabical pattern (CVC) and by a complex articulatory movement (in its several phonetic articulations*).

Attempting to understand the process of vibrant coda acquisition, several studies about this theme have been held focusing both on its typical and on its deviant acquisition, from different perspectives^(7,8,10-14).

Regarding the description of the vibrant coda typical acquisition in BP, a study⁽¹⁰⁾ showed that children commonly use a high percentage of repair strategies attempting to approach the target phonological system. According to the author's description⁽¹⁰⁾, the most commonly used repair strategies refer to semi-vocalization, substitution, epenthesis, besides the vowel lengthening.

A recent study⁽⁸⁾ described, with the use of acoustic analysis, that in the productions judged as having vibrant coda omission, the vowel lengthening is one of the compensation resources mostly used by children while attempting the target

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*The vibrant coda in BP can be carried out phonetically as voiced alveolar vibrant, voiceless alveolar vibrant, voiceless alveodental retroflex, voiced alveodental, palato-alveolar and palatal retroflex, voiced uvular⁽⁹⁾.

production. That indicates that the children already present some knowledge about this syllabical structure.

As for the description of the deviant acquisition of the vibrant coda, the author of a study⁽¹²⁾ identified and described, with the use of acoustic analysis, a meaningful discovery referring to the attempts of the child to approach the target production. Such discovery refers to the fact that many vibrant coda productions judged auditorily as being a categorical substitution of the semi-vowel /j/, being a phonic covert contrast, that is, a phonic contrast which is auditorily imperceptible, but detected acoustically or/and articulatorily⁽¹⁵⁾. In these “apparent” substitutions, the covert contrast was marked by the acoustic parameters of relative length, formant trajectories of F1, F2 e F3⁽¹²⁾. The non-detection of the covert contrast in the auditory-perceptual analysis is explained in the study by the fact that “our perception – related to the phonic units – is directed by the categories of the adult’s phonic system”⁽¹²⁾.

This way, in the studies mentioned, we verify the constant use of the acoustic analysis for a more detailed description of the process of vibrant coda acquisition, once it enables the apprehension of the covert contrasts (marked by the repair strategies) used by children. Such contrasts may seem to be constituent in the phonic acquisition process.

However, there is still a shortage of studies for BP which focus on the acquisition of typical vibrant coda, considering the way that children appropriate the acoustic-phonetic cues to reach the target contrasts of the language. Thus, the purpose of the present study is to describe and acoustically characterize the typical process of acquisition of the vibrant coda, in its approximant retroflex variable. Specifically, the objectives were: to acoustically characterize the children’s productions auditorily judged as typical vibrant coda (target); to identify the presence or not of covert contrasts in the productions of vibrant coda auditorily judged as omitted; and, when present, to characterize the way that these covert contrasts are acoustically marked in the speech.

We believe that the development of this study may contribute to the comprehension of the process of vibrant coda acquisition and provide further information about the presence of covert contrasts as a “phase” in the acquisition process of a determined phonological contrast. Moreover, it may bring contributions about which the acoustic parameters used by the children to mark the phonological contrast involving the vibrant coda in its approximant retroflex variety are.

METHODS

The productions of the vibrant codas were gotten from speech samples which integrate a Digital Acoustic Data Base organized by members of the Research Group of Studies about the Language (GPEL). The constitution of the referred data base was approved by the Research Ethics Committee from the Universidade Estadual Paulista “Júlio de Mesquita Filho” (UNESP Marília), under protocol number 132/2010.

The database consists of recordings of 120 children which attend one of the city’s Pre-schools called *Sítio do Pica-Pau Amarelo*. The recordings were made using high reliability

equipment, with each child individually, inside an acoustic booth installed in the school. In order to elicit the sample which constitutes the data base, we used the Speech Assessment Tool for Acoustic Analysis (IAFAC)⁽¹⁶⁾, which encircles the production of words containing all the phonemes of the phonological system of BP, considering both the attack position and the syllabic coda position. The words of the IAFAC were inserted in the carry sentence “*Say (target word) very beautifully*” so that the children could repeat them after simultaneously presenting the visual and auditory cues corresponding to the target words.

From this data base, recordings of 30 children attending the second year of the public preschool *Sítio do Pica-Pau Amarelo* were selected to be used in this research. The criteria for the subject’s participation were: to be between 3 and 4 years old; not to present neurological, cognitive and language disorders; to have normal hearing**; as well as to have a written authorization signed by the guardians, through the Free and Informed Consent Term.

The audio files related to the vibrant coda productions in the context of the stressed vowels /i/, /a/ and /u/ corresponding to the productions of the words “*circo*” (circus), “*carta*” (letter) and “*curto*” (short) were selected with the use of the PRAAT software. Also, the audio files related to the production of the words “*rico*” (rich), “*lata*” (can) and “*Pluto*”, since they constitute analog pairs to the target words. This last selection was done to enable the comparison of the syllabical rhyme of the words judged as having coda omission with the syllabical rhyme of the words whose coda position was not filled.

Specifically, the following comparisons were done to contemplate the three objectives of the research:

- [iɹ], of [‘siɹku], judged as target, opposed to [i], of [‘riku];
- [aɹ], of [‘kaɹta], judged as target, opposed to [a], of [‘lata];
- [uɹ], of [‘kuɹtu], judged as target, opposed to [u], of [‘plutu];
- [i], of [‘siku], judged as having coda omission, opposed to [i], of [‘riku];
- [a], of [‘kata], judged as having coda omission, opposed to [a], of [‘lata];
- [u], of [‘kuto], judged as having coda omission, opposed to [u], of [‘plutu].

Nevertheless, taking into account the recordings of 30 children, we came to a total of 180 performances, of which 90 are productions of words involving the filled coda position by the vibrant coda (30 recordings of children X 3 words: “*circo*”, “*carta*” and “*curto*”) and 90 are productions not involving the coda production (30 recordings of children X 3 words: “*rico*”, “*lata*” and “*Pluto*”).

After the sample selection, an auditory-perceptual characterization of the productions was held based on the transition made by five judges living in the same dialectal region of the current study. The judges transcribed the children’s productions, from three categories; target production, substitution and omission of the vibrant coda. An agreement criterion of 80% was adopted among the judges.

Afterwards, the acoustic analysis of all the samples was held with the use of PRAAT software. The parameters used in

the analysis were: measurement of the formant trajectory of the first, second and third formants (F1, F2 and F3 respectively), and absolute and relative length of vibrant coda, as described in a previous study⁽¹²⁾.

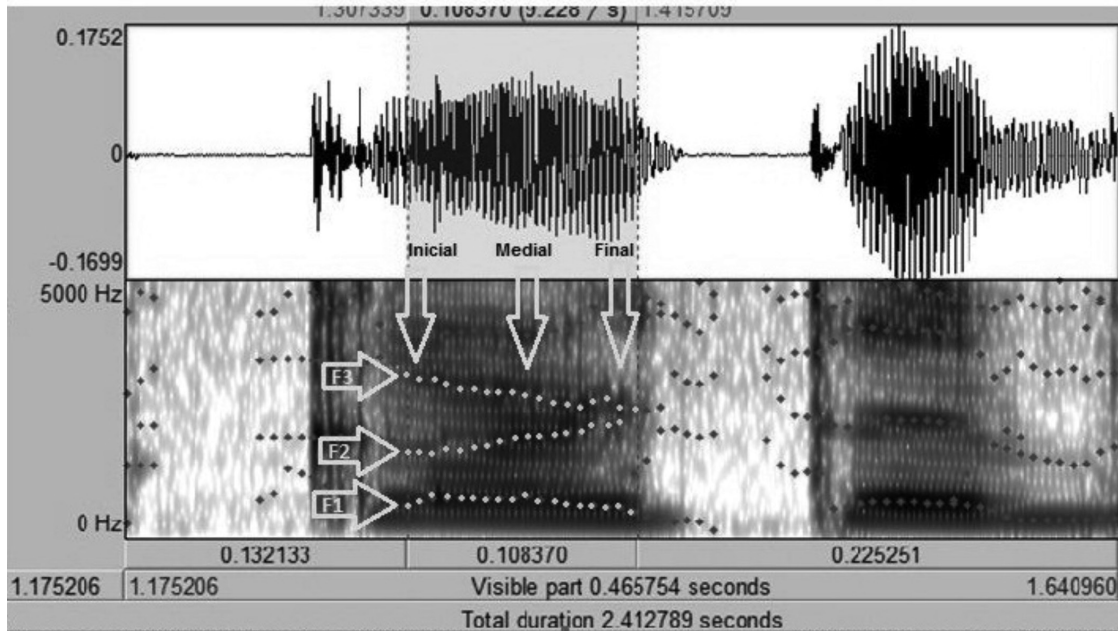
In order to obtain the measures of the formant trajectory, the values related to the initial, medial and final positions of the three formants (F1, F2 and F3) were considered, reviewing the moments which characterize both the vowel production and the retroflex production. The three moments were considered due to the fact that there isn't a defined fragmentation moment between the vowel and the retroflex, that is, it's not possible

to precisely determine the end of the vowel and the beginning of the retroflex.

Moreover, the distances between F3 X F2 X and F2 X F1 in the final position of the formant trajectory were calculated. This distance was obtained from the subtraction of the values: F3 – F2 in the final part of the trajectory, and F2 – F1 in the final position of the trajectory.

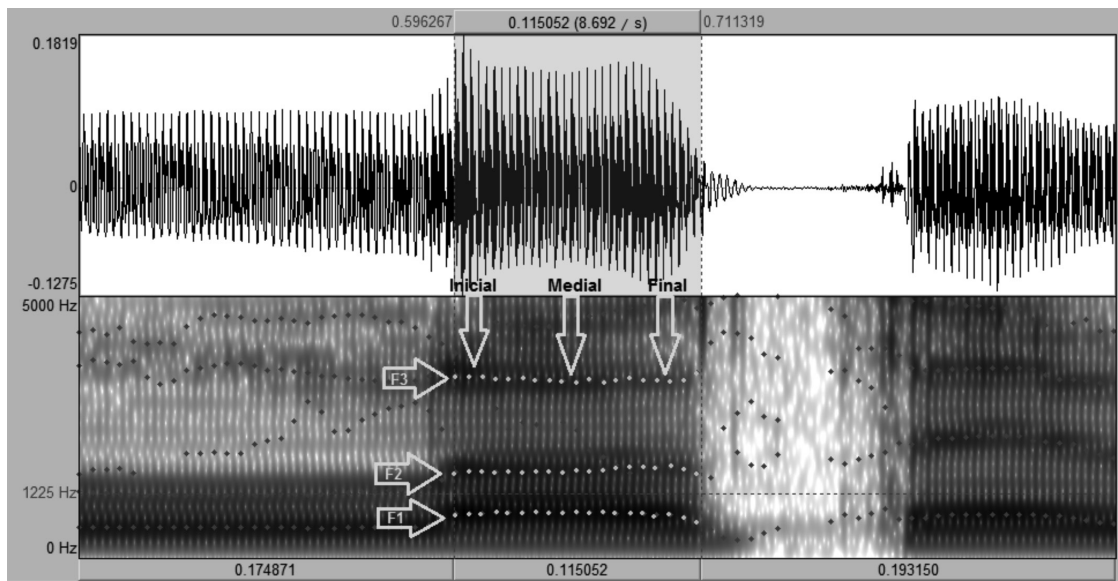
The formant trajectory of F1, F2 and F3 adopted in the analysis, are illustrated in Figures 1 and 2.

The length measurement used in the analysis was the vibrant coda relative length in the attempt to minimize variations



Obs.: The selected part corresponds to the rhyme of the first syllable of the word "carta"

Figure 1. Formant trajectory adopted in the analysis related to the production of the word "carta"



Obs: The selected part corresponds to the rhyme of the first syllable of the word "lata"

Figure 2. Formant trajectory adopted in the analysis related to the production of the word "lata"

of this parameter mainly due to the changes in the speech rate. For instance, in the word [‘kaʁta], the syllabical rhyme absolute length – [aʁ] (phonic element focused in the analysis) and the whole length of the word – [‘kaʁta], were calculated so that the relative length was calculated, according to the following equation: relative length = absolute length [aʁ] X 100/absolute length of the word [‘kaʁta].

Statistical analysis

The measurements of the formant and length trajectory were analyzed using the One-Way ANOVA test, along with the Statistica software version 7.0. The dependent variables considered were all the acoustic parameters used in the analysis, whereas the independent variables adopted referred to the position of filled and unfilled coda in the target words. After the One-Way ANOVA, the test post-hoc, the Hierarchical Linear Model, was used in order to determine the acoustic parameters and their magnitude in the distinction of the filled and unfilled coda position.

The results with p-values lower than 0.05 ($p < 0.05$) were considered significant. The results with p-values between 0.05 and 0.1 ($0.05 < p < 0.1$) were considered marginal.

RESULTS

Firstly, the results concerning the auditory-perceptual analysis will be presented, and afterwards the results obtained in the acoustic analysis will be exposed.

Auditory-perceptual analysis

The results of the perceptual- auditory characterization of the production of vibrant coda by the children in vowel context are presented in Table 1.

Table 1. Characterization of vibrant coda productions in the three vowel contexts, according to the perceptual-auditory analysis

Vowel context	Perceptual-auditory judgement			
	Target productions n (%)	Errors of production of the vibrant coda		Total n (%)
		Omission n (%)	Substitution n (%)	
/a/	25 (83.3)	-	5 (16.7)	30 (100)
/i/	22 (73.4)	8 (26.6)	0 (0)	30 (100)
/u/	24 (80)	3 (10)	3 (10)	30 (100)
Total	71	11	8	90

Acoustic analysis – productions judged as target

In the acoustic analysis of the productions judged as target we compared the values of the acoustic parameters of the productions judged as target to the values of the productions which did not present the position of filled coda. Illustrating, the acoustic measurements related to the rhyme of the first syllable of the word “circo” (equivalent to /iR/)

were compared to the rhyme of the first syllable of the word “rico” (equivalent to /i/). The results of this analysis are exposed in Table 2.

Table 2. Results of the productions judged as target in the perceptual-auditory analysis

Acoustic parameters	R ²	R ²	F value	p-value
	multiple	adjusted		
Vowel /i/				
% length	0.04	0.01	1.5	0.23
F3 medial	0.14	0.12	6.3	0.02*
F3 final	0.05	0.03	2.27	0.14
F3 final-F2 final	0.15	0.13	7.25	0.01*
F2 medial	0.39	0.38	25.7	0.00*
F2 final	0.29	0.27	16.24	0.00*
F2 final-F1 final	0.29	0.28	16.68	0.00*
F1 final	0.03	0.01	1.12	0.30
Vowel /a/				
% length	0.35	0.33	25.47	0.00*
F3 medial	0.08	0.057	3.97	0.05
F3 final	0.12	0.1	6.55	0.01*
F3 final-F2 final	0.45	0.44	39.35	0.00*
F2 medial	0.2	0.18	11.73	0.00*
F2 final	0.36	0.34	26.51	0.00*
F2 final-F1 final	0.62	0.61	78.99	0.00*
F1 final	0.47	0.46	42.71	0.00*
Vowel /u/				
% length	0.02	0.01	0.86	0.36
F3 medial	0.42	0.4	33.02	0.00*
F3 final	0.49	0.48	43.95	0.00*
F3 final-F2 final	0.64	0.63	80.85	0.00*
F2 medial	0.06	0.04	2.8	0.1
F2 final	0.11	0.09	5.68	0.02*
F2 final-F1 final	0.15	0.14	8.4	0.01*
F1 final	0.07	0.05	3.64	0.06

*Significant values ($p < 0.05$) – One-way ANOVA

We, therefore, verify that in the context of the vowels /i/ and /u/, five out of the eight acoustic parameters were sensitive to differentiate the syllabical rhyme containing the vibrant coda and syllabical rhyme without the filled coda position. In the context of the vowel /a/, we verify that the greatest part of the acoustic parameters (seven out of the eight parameters) was used to mark the filling of the vibrant coda. We also highlight that both the p-values and the F values of the acoustic cues varied in their magnitude, that is, there are acoustic parameters that present higher F value and consequently, higher statistical significance.

Acoustic analysis – productions judged as having omission

In the context of the vowels /i/ and /u/, the values of the acoustic parameters of the productions judged as having

omission of the vibrant coda were compared to the values of the acoustic parameters of the productions of the words which did not have filled coda position. Illustrating, the values related to the rhyme of the first syllable of the word [‘siku], judged as coda omission (equivalent to /i/), were compared to the values of the rhyme of the first syllable of the word “rico” (equivalent to /i/). Table 3 summarizes the results obtained in this comparison. We call the reader’s attention to the context of the vowel /a/, not analyzed due to the fact that it didn’t present any vibrant coda production judged as omitted.

Table 3. Results for the productions judged as omission in the auditory-perceptual analysis

Coefficients	R ² multiple	R ² adjusted	Valor de F	Valor de p
	Vowel /i/			
% length	0	-0.07	0.04	0.84
F1 final	0	-0.07	0	0.99
F2 - F1 final	0.01	-0.06	0.19	0.67
F2 medial	0.2	0.14	3.47	0.08**
F2 final	0.01	-0.06	0.18	0.68
F3 - F2 final	0.02	-0.05	0.34	0.57
F3 medial	0	-0.07	0	0.96
F3 final	0.02	-0.05	0.31	0.58
Interception	-	-	719	0.00*
Vowel /u/				
% length	0.84	0.77	10.87	0.08**
F1 final	0.14	-0.28	0.34	0.62
F2 - F1 final	0.34	0.01	1.02	0.42
F2 medial	0.29	-0.06	0.82	0.46
F2 final	0.3	-0.05	0.87	0.45
F3 - F2 final	0.39	0.09	1.29	0.37
F3 medial	0.1	-0.35	0.22	0.68
F3 final	0.03	-0.46	0.05	0.84
Interception	-	-	882344.7	0.00*

* Significant values ($p < 0.05$) – One-way ANOVA

** Marginal values ($0.05 < p < 0.1$) – One-way ANOVA

We verify, in the context of the vowel /i/, that the interception of the group of parameters along with F2 in medial position, are relevant to mark the distinction between the “apparent omission” of vibrant coda and the unfilled coda position. As for the context of the vowel /u/, we observe that both the interception of the parameters and the relative length (even with marginal p-value) were used to distinguish the “apparent omission” and the position of the unfilled coda.

DISCUSSION

Considering the auditory-perceptual judgment of the children’s productions, we verify the general tendency of 77.8% of the productions were judged as target, 12.2% as omitted and 10% as substituted, matching the previous study⁽¹⁰⁾, which describes that the acquisition of the medial vibrant coda occurs at around 3 years and 10 months. Another

result to be highlighted in the auditory-perceptual analysis refers to the fact that the omissions, in general, are more repetitive than the substitutions. This discovery agrees once more with the previously cited study⁽¹⁰⁾, which describes that the strategy of omission is very frequent in the acquisition of medial vibrant coda. This fact is possibly explained both due to the syllabical preference (CVC) and to the articulatory preference^(3,4,7,8).

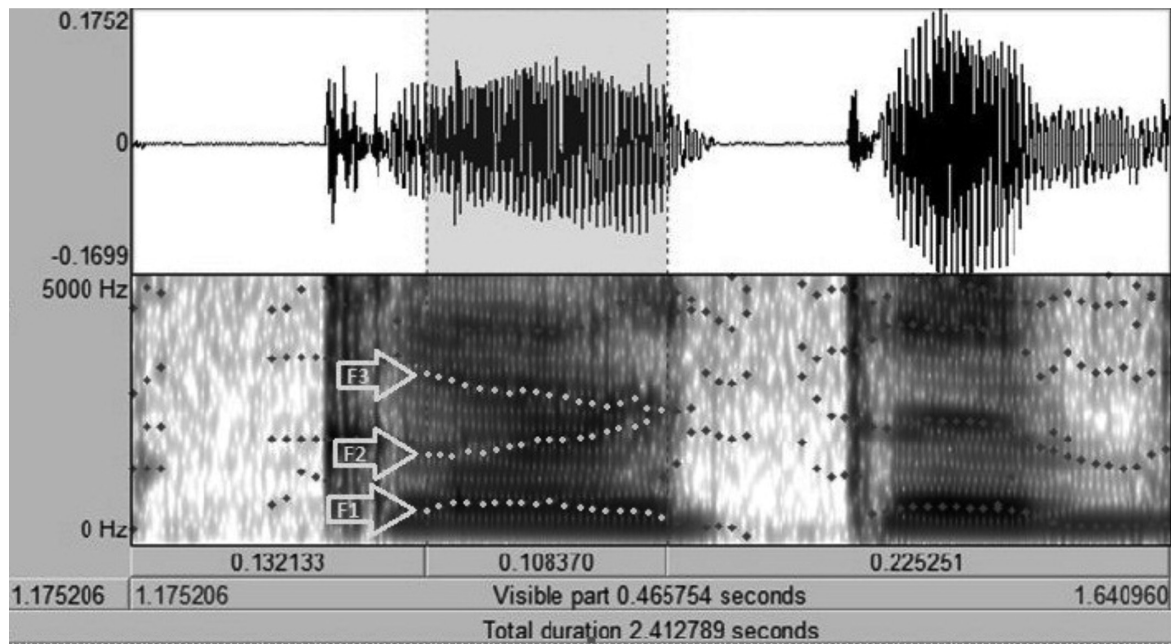
As described, the results of the perceptual- auditory judgment varied according to the vowel context. The context of the vowel /a/, specifically, seems to favor the acquisition, seeing that 83% of the productions were judged as target, 17% as substituted, not showing productions judged as omitted. These results agree, mostly, with previous researches^(5,8). In the first study⁽⁵⁾, we could observe that the vowel contexts /a/ and /o/ present greater incidence of correct productions of the liquid non-lateral. In the second study⁽⁸⁾, we verified that the combination of occlusive sounds with the vowel /a/ facilitates the acquisition of the /R/ coda. However, these discoveries disagree with those found in a previous study⁽¹⁰⁾, in which the most favorable contexts to the production of the medial coda referred to the /ε/ and /i/, instead of the /a/.

Regarding the acoustic analysis of the productions judged as target, we verified that not all the acoustic parameters were used to mark the contrast of the filled and unfilled syllabical rhyme by the vibrant coda. Particularly, in the context of the vowel /a/, 87.5% of the parameters (seven out of the eight parameters) were used to mark the production of vibrant coda, while in the context of the vowels /i/ and /u/, only 62.5% (five out of the eight parameters) presented significance.

This discovery is possibly justified due to the neuromaturation issues. The children participating of this study were in the process of neuro-motion maturing, not yet presenting stability in the speech production. Previous studies, for instance, alert to the fact the neuro-maturing of the orofacial structures is a process that may interfere in the speech production, once it’s directly linked to the mobility of structures, such as the tongue and the lips, necessary and indispensable to the speech production⁽¹⁷⁻²⁰⁾.

A second highlight referent to the acoustic characterization of the target productions is about the type of magnitude of the acoustic cues used by children. We observed that the children do not use acoustic cues in an equivalent way, suggesting an organizational hierarchy of such cues, such as described in previous studies⁽²¹⁻²³⁾.

From the post-hoc statistical analysis, we infer that the greater the p and F values obtained in each acoustic parameter, the greater the robustness in the differentiation of the syllabical rhyme that presents vibrant coda and the syllabical rhyme that does not present the filled coda position. This way, it’s possible to determine which the most and least robust acoustic parameters in the differentiation of the contrast between the filled and unfilled vibrant coda positions are. In another way, we observe that there are acoustic parameters which may be characterized as primary acoustic cues – parameters that present a greater magnitude of p and F values, and acoustic parameters that present a smaller magnitude of p and F values in the differentiation of the syllabical rhyme with and without the filling of the vibrant coda.



Obs: The selected part corresponds to the rhyme of the first syllable of the word “carta”, in which a rising in F3 can be observed, which is characteristic of the retroflex movement present in the syllabic coda production and the simultaneous rising movement of F2.

Figure 3. Wave shape and spectrogram of a target production of the word “carta”

Considering all the vowel contexts, we propose how primary acoustic parameters (primary cues) are used to characterize the vibrant coda production, in its retroflex approximant variable, the difference between the trajectory final position of F3 and F2, and the difference between the trajectory final position of F2 and F1, corresponding to the acoustic pattern of descending movement of F3 simultaneously with the ascending movement of F2. These primary parameters, illustrate the repetitive use of the following acoustic patterns identified in the analysis of the target productions: falling movement of F3 and rising movement of F2, according to the example presented in Figure 3.

As secondary acoustic parameters we propose: the measurement of F2 in the medial position of the formant trajectory, the measurement of F3 in the medial position of the formant trajectory and the measurement of F3 in the final position of the formant trajectory.

Although for the American English the acoustic parameters described as the most important to characterize the retroflex approximant production is the falling of F3⁽²⁴⁾, studies which describe the retroflex approximant production in BP^(12,25) found a standard similar to the one described in this study, that is, approximation of the formant trajectories of F3 and F2, not necessarily only due to the falling of F3, but also to the simultaneous elevation of F2. More recently, another study⁽²⁶⁾ described the important role of the trajectory of F2 in the characterization of the lateral and non-lateral liquid sounds in BP, from the children’s speech production.

A last remark refers to which acoustic parameters are used by children in typical and deviant process of acquisition to mark the covert contrast. We identified, therefore, that the interception of the parameters, the length and measurement of medial

F2 characterize the presence of covert contrast in the children in typical process of acquisition. It means to say that, in general, if we consider the analysis in the vibrant coda productions judged as omitted, there’s only one parameter, individually, that won’t be sensitive enough to detect such distinction.

This way, considering the group of acoustic parameters, we identify the presence of covert contrast in both vowel contexts, in the productions of vibrant coda judged as omitted. Similarly, according to a previous study⁽¹²⁾, the acoustic parameters used by children in deviant acquisition process were, preferably, the use of the trajectory and the length of F2. Nonetheless, the detection of covert contrast in the productions judged as omitted is extremely relevant to the phonological acquisition area, in that it allows to explicit the way by which the children gradually master the acoustic parameters to establish a determined phonic contrast.

CONCLUSION

From the development of this research, we highlight four main results: the children mostly produce the targets they omit or the ones they substitute; the context of the vowel /a/ shows itself as the most facilitator to the vibrant coda production, in its retroflex approximant variable; the primary acoustic parameters (that is, the most important) to the characterization of such structure were the falling formant trajectory of F3 and rising formant trajectory of F2; there are covert contrasts in the “apparent omissions”, acoustically marked by the interaction of the parameters of length measurement and F2 in medial position of the trajectory.

Additionally, the acoustic analysis show a necessary resource for the description and characterization of the way

which children start mastering the acoustic-phonetic cues until they reach the effective contrast of vibrant coda. The identification and description of such cues may subsidize the clinical practice both in the characterization of the deviant production of vibrant coda by children with phonological disorder and in the acquisition of such structure by these children during the therapeutic process.

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RESUMO

Objetivo: Caracterizar acusticamente as produções da coda vibrante julgadas auditivamente como alvo; identificar a existência ou não de contrastes encobertos, nas produções julgadas auditivamente como tendo omissão da coda vibrante; e, quando existentes, caracterizar de que modo são marcados acusticamente na fala. **Métodos:** Foram extraídas de um banco de dados, com o uso do *software* PRAAT, palavras produzidas por 30 crianças (3-4 anos) em desenvolvimento normal, que continham a coda vibrante medial na sílaba tônica, no contexto das vogais /i/, /a/ e /u/. Após a caracterização perceptivo-auditiva das produções, realizou-se uma análise acústica a partir das trajetórias formânticas (F1, F2 e F3) e duração relativa da sílaba que envolvia a coda vibrante. Os dados foram estatisticamente analisados. **Resultados:** Na análise perceptivo-auditiva, 77,8% de produções foram julgadas como alvo, 12,2% como omitidas, e 10% como substituídas, variando em função do contexto vocálico. Na análise acústica das produções alvo, verificou-se que as crianças utilizam preferencialmente os parâmetros relativos à trajetória formântica de F2 e F3 para marcarem a aquisição dessa estrutura. Analogamente, na análise acústica das produções julgadas como omitidas, constatou-se a presença de contrastes encobertos, marcados pela intercepção dos parâmetros adotados. **Conclusão:** A análise acústica mostra-se um recurso necessário e imprescindível para a descrição e caracterização do modo pelo qual as crianças iniciam o domínio das pistas fonético-acústicas até atingirem o contraste efetivo da coda vibrante.

Descritores: Acústica da fala; Criança; Linguagem infantil; Fonética; Medida da produção da fala

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