TYPICAL AND ATYPICAL PHONOLOGICAL ACQUISITION OF CCV SYLLABIC PATTERN: ACOUSTIC AND ARTICULATORY DATA

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- ABSTRACT: The main purpose of this study is to characterize the production of words with the target-syllables CCV and CV types in children with typical and atypical phonological development. The hypotheses were: H1 - the production of target words with CV and CCV syllable of the typical children would present different ultrasound and acoustic measurements; H2 - ultrasound and acoustic measurements could differentiate the clinical condition of the children; H3 - children with atypical production could present differences in ultrasound and acoustic measurements between the CCV targets (being the rhotic in the position of C2) and CV (CCV aurally judged as CV). Ten children recorded words with the target-syllables CCV and CV. Subsequently, perceptive, acoustic, and ultrasound analysis were performed (ratios between tip and blade of the tongue (TT/BT), tip and dorsum of the tongue (TT/DT) and blade and dorsum of the tongue), being analyzed by repeated measures ANOVA. The H1 was corroborated by the ratios between TT/BT, TT/DT and BT/DT, indicating that typical children produce higher elevation of tip and blade of tongue on the CCV target-syllable when compared to the CV target-syllable. The H2 and H3 were partially confirmed by the ratio between TT/DT and BT/DT and between TT/DT and BT/DT, respectively. The results suggest that children with typical development seem to be in the direction of the target production, since, in CCV patterns, a higher elevation of TT and duration occurs when compared to the CV syllable. For atypical children, the ratios between TT/DT show that they have a tip of tongue elevation of 18.23% in the CCV target syllables, while in the CV target syllable it is 13.58%, suggesting the presence of TT elevation to produce the tap sound with reduced magnitude and non-overlapping gestures of the CCV target, as well as undifferentiated gestures.

- KEYWORDS: Articulatory Analysis. Language Acquisition. Acoustic Phonetics. Brazilian Portuguese.

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Introduction

The current version of Gestural Phonology[1] proposes a specific intergestural coordination pattern for each type of syllabic pattern, modeled from coupled oscillators (NAM; GOLDSTEIN; SALTZMAN, 2003; GOLDSTEIN et al., 2007a). In this model, each gesture would be associated to the planning of a non-linear oscillator[2]. Using metaphorically the example of the pendulums of a clock to explain this effect, it is observed that a pendulum does not work alone. In contrast, it is always connected to another pendulum. This means, in gestural terms, that one gesture is always "joined" to another gesture. When the pendulums move simultaneously in the same direction, they are said to coordinate in phase or in synchrony; when they move in opposite directions, they are said to coordinate in antiphasis (ALBANO, 2012).

Thus, Gestural Phonology establishes a type of organization between gestures, depending on the type of syllabic pattern (consonant vowel - CV, vowel consonant - VC, and consonant, consonant and vowel - CCV), prescribing phasing relationships between the gestures involved and a specific type of organization for each type of syllable. There are three patterns of intergeneric coordination involving the syllabic structure, namely: the coordination of the CV target syllable, the coordination of the VC target syllable and the coordination involving the CCV target syllable (NAM; GOLDSTEIN; SALTZMAN, 2003).

In the CV target syllable, the constrictions that configure the vocal tract in the consonant and vowel production begin from synchronic or phase mode. For example, in producing the syllable /ba/, the gestures involved in the consonant and vowel productions begin concurrently, that is, lip closure for /b/ and pharyngeal narrowing for the production of /a/ at the same time, establishing a phase relation between these two gestures involved. In the VC target syllable, the gestures involved in the production of V and C present a phasing relation in antiphasis. This is because the activation of the C gesture is activated after the activation of the V gesture (NAM; GOLDSTEIN; SALTZMAN, 2003; GOLDSTEIN et al., 2007a).

In the production of target syllables with complex onset of the CCV-type, it is assumed that both types of coordination are expected to be present: both in-phase coordination and antiphase coordination (NAM; GOLDSTEIN; SALTZMAN, 2003; GOLDSTEIN et al., 2007a). The mode in which the gestures are coordinated in the target syllables of the CCV type can be illustrated in Figure 1, below.

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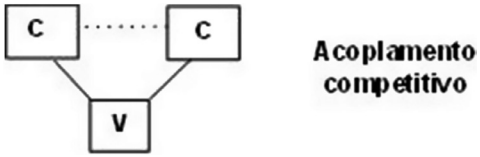
[1] Gestural Phonology, initially proposed by Browman and Goldstein (1986, 1989, 1990, 1992, 2000), lists as primitive unity of speech production the called articulatory gesture, which is endowed simultaneously with physical and symbolic nature.

[2] The classic example is the pendular movement of the clocks.

Figure 1 – Gestural organization for complex onsets. Continuous lines represent in-phase, while dotted lines refer to the antiphasis.



Source: Adapted from Marin and Pouplier (2010).

Figure 1 illustrates how intergestural coordination occurs in the production of the CCV target syllable: while the consonants establish an antiphasis relation between each other (dotted lines), both consonants (C1 and C2) have a phasis relation with the vowel (continuous line) (MARIN; POUPLIER, 2010). The antiphasis relation is due to the competitive coupling of the consonant gestures, which cannot happen simultaneously, in order to rescue the distinctiveness between gestures (BROWMAN; GOLDSTEIN, 2000).

From the above, it can be inferred that the production of vowel consonant syllables involves a more stable coordination pattern between C and V articulatory gestures, whereas the production of consonant, consonant and vowel (CCV) syllables involve a more complex and less stable gestural coordination pattern.

From the point of view of syllabic acquisition, the coupling between the articulatory gestures involving the production of CV target syllable results in a more stable coordination pattern in the sense that the C and V gestures are produced in-phasis or synchronously. This means that the consonantal gesture initiates the trajectory at the same time as the vowel gesture, which makes coordination more stable and easier to acquire, compared to the more complex syllabic patterns (coda (VC)) and complex onset (CCV)) (GOLDSTEIN et al., 2007a). In the case of complex target syllables (CCV), as it is seen, there is competition between C1 and C2 consonants, caused by the strong coupling between CV, making the learning of this coordination between CCs difficult (NAM et al., 2009).

These universal suppositions about intergestural coordination within the syllable corroborate the premise that there is a preference for the CV syllabic pattern in the majority of languages, with the evidence that, during phonological acquisition, the CV structure is typically acquired prior to the structures of VC (NAM et al., 2009) and CCV types (LAMPRECHT et al., 2004), which may also be justified by the stability between the involved gestures in the production of the CV syllable. According to Gestural Phonology, simplifications of the target syllable CCV to CV could be associated with the overlapping of the adjacent gestures and/or the reduction of the magnitude of gestures related to C2 production (BROWMAN; GOLDSTEIN, 1992, 2001).

To study this phenomenon of cluster simplification, Ardestani (2013) analyzed words in rhyme position from Persian through acoustic data and ultrasound data from

the speech of ten adults. The researcher investigated the production of habitual speech that occurs in the clusters involving the coronal [t] preceded by obstruents or nasals (CC) /ræbt/ → [ræb], /zæbt/ → [zæb], /væqt / → [væχ]. For this, the articulatory measure used (the distance between the tongue and palate trajectory) allowed to measure the magnitude of the gesture of /t/, which aurally seemed to be excluded, but was still present, sometimes with reduced magnitude of the articulatory gesture, corroborating the prediction of the Gestural Phonology (BROWMAN; GOLDSTEIN, 1992, 2001) concerning the syllable simplification which target is CCV to CV (described above). The author also found different degrees of reduction of the /t/ gesture: complete, partial and zero. The study showed that, in this phonological phenomenon from Persian, both the gestural overlapping and the [t] gesture with reduced magnitude are present. Ardestani's study (2013) corroborates two principles of Gestural Phonology: the use of gestural units as primitive of a phonological model, with the incorporation of the dynamic properties of these units; and its coordination process.

Similarly, the processes of clusters simplification occur in typical and atypical phonological acquisition. In this way, since the CCV target pattern requires a greater degree of articulatory and phonological complexity - compared to other syllabic types, being CV or VC - some children do not get to acquire the CCV pattern at the expected age (between 5[3] and 7[4] years of age), reducing the CCV target to the CV target syllable, occurring the so-called "clusters simplification".

The use of articulatory analysis instruments allows a more detailed analysis of speech production, allowing the incorporation of phonetic detail in the speech analysis (ALBANO, 2001), as in the study previously cited (ARDESTANI, 2013). Among the articulatory analyses available for analysing speech production (Magnetic Resonance Imaging (MRI), X-rays, Micro-X-ray and Magnetic Resonance) (STONE, 2005; RIDOUANE, 2006), the ultrasound analyses of the tongue movement are highly recommended to investigate speech "errors", since the image of the tongue contour provides information for the direct visualization of the articulators, specifically the tongue, involved during the phonic productions. In addition, it is a non-invasive, safe, fast and inexpensive technique.

Due to the lack of articulatory studies involving the simplification of the CCV to CV target during the phonological acquisition process, the purpose of the present study is to characterize the production of target words with CCV versus CV syllabic patterns in children with typical and atypical phonological development. For this purpose, the following hypotheses should be confirmed:

H1: The production of target words with CV and CCV syllabic patterns in typical children would present different ultrasound and acoustic measures (duration). Since these children effectively produce the contrast between CV and CCV, it is expected that the articulatory and acoustic measures will differentiate the production of the target

[3] Lamprecht et al. (2004).

[4] Wertzner (2000).

words containing these syllabic structures. H2: Ultrasound measures (ratio between tip and blade of the tongue, between tip and dorsum of tongue and between blade and dorsum of tongue) and acoustic (duration) of target words with CV and CCV syllabic structures could differentiate the clinical condition of the children, demonstrating or revealing differences in gestural coordinates.

H3: Children with atypical production could present differences in ultrasound and acoustic measures (duration) in the comparison of the production of the target words with the CCV and CV syllables, although CCV was aurally judged as CV. According to Gestural Phonology, it is possible to record the presence of articulatory gestures of reduced magnitude even in productions judged aurally as simplified. Therefore, it is expected to find some difference in the articulatory and/or acoustic measures between the CCV and CV targets in the production of children with atypical phonological development.

Method

Participants

Ten children, speakers of Brazilian Portuguese (BP), residents in the city of Marília (São Paulo), being five children with typical phonological development (TC) and five with atypical phonological development (PD) (presenting reduction of clusters according to the auditory-perceptual judgment). For both groups of children, the exclusion criteria were: absence of intellectual and neurological alterations; absence of anatomo-morphological alterations that compromise the speech production process (such as lip-palate cleft); and absence of otologic/auditory alterations. Chart 1 presents the characterization of the ten children participating in this research.

Chart 1 – Characterization of the children who participated in the research.

Children's Clinical Condition	Subject	Gender	Age Group
Typical	E.C.F.S.	Female	5 years and 4 months
Typical	K.C.F.S.	Female	6 years and 8 months
Typical	L.	Female	5 years and 6 months
Typical	L.F.O.V.	Male	6 years and 3 months
Typical	M.O.C.	Female	6 years and 2 months
Atypical	B.F.	Female	6 years and 0 months
Atypical	E.M.P.D.	Male	6 years and 9 meses
Atypical	G.D.O.	Male	6 years and 7 months
Atypical	N.G.F.S.	Male	5 years and 5 months
Atypical	M.F.	Female	5 years and 0 months

Source: author's elaboration.

The study was approved by the Research Ethics Committee of the Faculty of Philosophy and Sciences – UNESP/Marília (Faculdade de Filosofia e Ciências – UNESP/Marília), under protocol nº. 0974/2014.

Material and *corpus*

The subjects were individually recorded in a single session of approximately 30 minutes in the Acoustic Analysis Laboratory – AAL (Laboratório de Análise Acústica – LAAc) of UNESP at the Marília campus (São Paulo, Brazil).

The recordings were performed using a portable ultrasound device (model DP 6600) located in a booth acoustically treated with the following equipment: unidirectional microphone, micro-convex transducer coupled to a computer and a head stabilizer (SCOBBIE; WRENCH; VAN DER LINDEN, 2008). Data capture was performed using the Articulate Assistant Advanced (AAA) software (ARTICULATE INSTRUMENTS, 2014), which hosts the ultrasound device and allows the analysis of ultrasound and acoustic signals obtained from speech recording in real time (RIDOUANE, 2006).

The children recorded a corpus with nine pairs of words containing the CCV and CV target syllables: broa/boa [ˊbɾoa/ ˊboa], prato/pato [ˊpɾato/ˊpato], prego/pego [ˊpɾɛgo/ˊpɛgo], pressa/peça [ˊpɾɛsa/ˊpɛsa], bruxa/bucha [ˊbɾuʃa/ˊbuʃa], frita/fita [ˊfɾita/ˊfita], grato/gato [ˊgɾato/ ˊgato], troca/toca [ˊtɾɔka/ˊtɔka], (MIRANDA; SILVA, 2011). We decided to catalogue the corpus proposed by Miranda e Silva (2011), since the pair of words catalogued obeyed the high lexical frequency in Brazilian Portuguese.

It should be emphasized that in Brazilian Portuguese the second consonant of the clusters can be filled by the lateral liquid (/l/) or the non-lateral liquid (rhotics) (/r/). There is a consensus in the literature (RIBAS, 2004; MEZZOMO et al., 2013) that the lateral liquids are acquired before the non-lateral liquids, and these are stabilized in the child's phonological system by the age of five years. For these reasons, in this study, we decided to define a methodological design and to deepen the study of clusters acquisition composed by the rhotic liquid called tap.

The target words were represented by pictures and presented in the AAA software. Initially, all pictures were presented in order to certify the understanding of the target word. For each word, the subjects were requested to perform three repetitions, totaling 540 stimuli (3 repetitions x 5 TCs x 5 ACs x 9 words with CCV + 9 words with CV). The stimuli were randomly arranged in the attempt to avoid responses patterns at judging.

Data analysis

Perceptive analysis

The speech productions recorded by the AAA software were submitted to perceptive judgment by expert judges residing in the same dialectal region as the participants.

Three speech-language pathologists with experience in phonetic transcription performed the perceptive judgment of the data. The speech samples provided to the judges were recorded words containing the minimum pairs (CV x CCV) produced by children with atypical phonological development.

Each judge received a total of 540 words (18 words - CV and CCV x 3 replicates x 10 subjects) arranged in an Excel spreadsheet with the sound files attached in the spreadsheet itself. Upon hearing the sound stimulus, the judge was asked to respond between CCV, CV or the other option (in that case, it would be necessary to transcribe the sound perceived by the judge). The agreement of at least 2 (66%) judges was considered for each evaluated stimulus.

Duration analysis

The sound files were edited and recorded in the AAA software and then exported and analyzed by PRAAT software (BOERSMA; WEENINK, 2014). The acoustic parameters adopted in the analysis were the absolute duration of the CCV and CV syllables and the relative duration of the syllabic pairs analyzed.

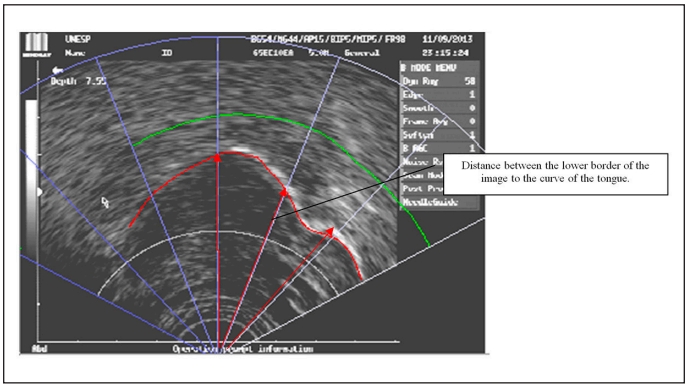
In the PRAAT software, inspection, labeling and segmentation of the audio files were performed. The segmentation was performed from the following criteria: /p/, /t/, /g/: the duration measure of the stretch between the burst acoustic record of the stops consonant until the end of the subsequent vowel, that corresponds to the final formants, was extracted; /b/: the beginning of segmentation for this sound also started in the burst and the end was delimited by the vowel formants; e /f/: the beginning of the segmentation for this sound also started in the fricative noise and the end was delimited by the vowel formants.

Articulatory analysis

For the ultrasound analysis, initially, a visual inspection of the recordings was performed in order to discard the ultrasound files with problems in the image quality. Then, the tongue contour was drawn semi-automatically through resources provided by the AAA.

The articulatory measures extracted were: distances of the tongue to the limit of the ultrasound image and area between the tip and the dorsum of the tongue. The measures of tongue distance up to the limit of the ultrasound image were: (i) between the tip of the tongue to the lower limit of the ultrasound image; (ii) between the blade of the tongue and the lower limit of the ultrasound image; (iii) between the dorsum of the tongue to the lower limit of the ultrasound image, being that the fixed reference point adopted for the measures was the lower limit of the ultrasound image, since this point is always the same in all subjects, regardless of size of the vocal tract, as can be seen in Figure 2:

Figure 2 – The arrows indicate the distance measurement by AAA, from right to left; the fans correspond to the tip of the tongue, blade of the tongue and dorsum of the tongue.



Source: author's elaboration

For each distance measured, a relative measure was developed, aiming to normalize the different sizes of the children's vocal tract. For this, three ratios considering the relation between the tip of the tongue and blade of the tongue were calculated; between the tip of the tongue and dorsum of the tongue; and the blade and the dorsum of the tongue. Thus, to obtain the measure of the ratio, the distance of the tip of the tongue was divided by the distance of blade of the tongue, and that result of the ratio (Rr) is multiplied by 100 and then subtracted from 100 (Ratio = Rf* 100-100). The other measures (tip of the tongue/dorsum of the tongue and blade of the tongue/dorsum of the tongue) were also submitted to this mathematical calculation. The equation described previously intends to transform the gross value (in distance) to a normalized value (a relation between two distances). Thus, the ratio consists of dividing one distance by the other (tip of the tongue and dorsum of the tongue, for example), indicating the relation between the first and the second measure; then, by multiplying the result of the ratio by 100, the decimal number in percent is modified. Finally, subtracting the value of 100 sets a positive or negative value depending on the denominator, whether it is higher or lower[5] than the numerator. For example, the positive ratio value between tip and the blade of the tongue means that the tip of the tongue is in a higher position when compared to the blade, while the negative value of the relation means that the tip of the tongue is lower than the blade.

[5] If the distance from tip of the tongue to the lower limit of the ultrasound is 40.70 mm and the dorsum of the tongue is measured by 41.84 mm, the ratio of the two values mentioned is 0.97. Then, by multiplying by 100, the value becomes a percentage, but it does not mean that the ratio is 97%. Therefore, it is necessary to subtract from 100 to obtain the value related to the relation between the two measures, resulting -2.71. In this case, the dorsum of the tongue is higher than the tip of the tongue.

The temporal parameter selected for the extraction of the distances corresponds to seven frames[6] before the burst and three after burst. With this time period selected, the articulatory measures were extracted from the maximum point of constriction of the tongue.

Statistical analysis

The software used in the statistical analysis was SPSS (version 22.0). For the descriptive statistics, mean values, standard deviation and coefficient of variation of duration and articulatory measures were extracted.

In relation to the quantitative analysis of acoustic and articulatory data, Two-Factor Analysis of Variance (ANOVA) for repeated measurements was performed. For the acoustic and articulatory measures, the syllabic patterns (CCV and CV) were used as an inter-subject variable; and as an intra-subject variable, the clinical condition (typical and atypical) of the children.

Results

Perceptive analysis

The children with typical phonological development produced 135 target words whose onset is formed by CCV and 135 target words whose onset is formed by CV. The judgments made by the judges confirmed the typical production of this group, since 135 (100%) of the CCV target structure productions were evaluated as CCV, while 135 (100%) of the CV target productions were evaluated as CV.

Analogously, the children presenting atypical phonological development produced 270 target words. However, of the 135 (100%) productions whose target structure is composed of CCV, 135 (100%) were judged as CV; and 135 (100%) of the target structure productions composed of CV were also evaluated as CV.

Duration analysis

We measured, from each subject, the absolute duration (in milliseconds) and the relative duration from the phonics production of the CCV and CV target syllables from the three selected repetitions. The measurements were submitted to descriptive statistics (mean, standard deviation and coefficient of variation) and the ANOVA test statistic to Repeated Measures. In Table 1, the values of the means and standard deviation of both groups are arranged.

[6] Refers to each of the images that compose the ultrasound video.

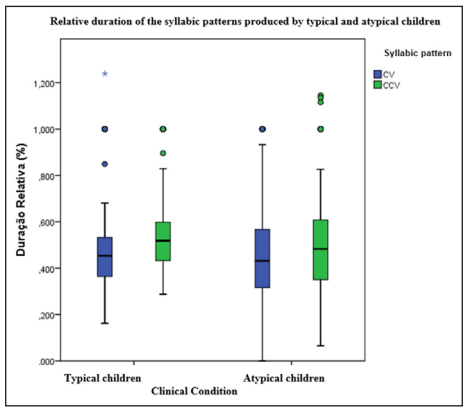
Table 1 – Descriptive statistics (mean and standard deviation) of the absolute and relative duration of the syllabic patterns of each group of children.

	Typical Children			Atypical Children		
	Absolute duration (ms)	**Relative duration (%)**	**Standard deviation**	**Absolute duration (ms)**	**Relative duration (%)**	**Standard deviation**
CCV Target	317	0,54	95	249	0,49	82
CV Target	265	0,50	95	227	0,46	62

Source: author's elaboration

For the relative duration, the repeated measures ANOVA demonstrated a significant difference in the main effect of the syllabic pattern ($F=8.85$, $df=1.6$, $p<0.00$) and in the clinical condition ($F=6.61$, $df=1.6$, $p<0.01$). The interaction between the syllabic pattern and the clinical condition showed no significant difference ($F=0.15$, $df=1.6$, $p=0.7$). The post hoc test demonstrated that the CCV target syllables are higher than CV in both clinical conditions, which can be evidenced in Figure 3:

Figure 3 – Box plot of relative duration of the syllabic patterns (CV in blue and CCV in green) produced by typical and atypical children. The x-axis represents the clinical condition of the subjects and the relative duration values (%) are found in the y-axis.



Source: author's elaboration

Articulatory analysis

Results related to the ultrasound analysis of the measures involving the ratio between the tip and blade of the tongue, the tip and dorsum of the tongue, as well as the blade and dorsum of the tongue are shown in Table 2.

Table 2 – Descriptive statistics (mean and standard deviation) of ultrasound measurements of the syllabic patterns of each group of children.

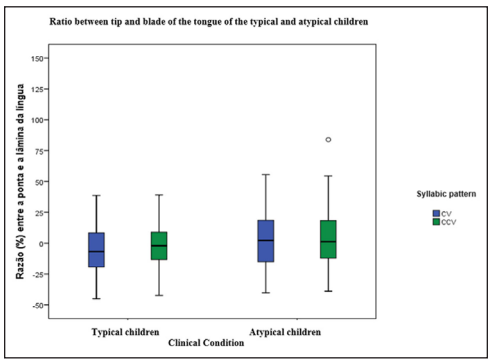
Corpus	Typical Children						Atypical Children					
	Tip/Blade of the tongue		Tip/Dorsum of the tongue		Blade/Dorsum of the tongue		Tip/Blade of the tongue		Tip/Dorsum of the tongue		Blade/Dorsum of the tongue	
	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
CCV Target	-2	16,86	18,23	21,16	20,94	9,38	4,38	20,97	35,02	26,91	30,07	12,46
CV Target	-5,56	19,27	13,58	24,89	19,9	11,03	3,17	20,07	33,4	25,89	29,97	12,35

Source: author's elaboration

The positive value of the ratio between the tip and blade of the tongue means that the tip of the tongue is in a higher position compared to the blade (as is the case of the rhotic production in CCV and CV targets in the atypical child), while the negative value of the ratio means that the tip of the tongue is in an inferior position to the blade of the tongue (as is the case of the typical child).

For the ratio between the tip and blade of the tongue, repeated measures ANOVA showed a significant difference in the main effect of the syllabic pattern ($F=4.75$, $df=1.7$, $p<0.03$), but there was no difference for the effect of the clinical condition ($F=3.63$, $df=1.7$, $p<0.06$). The interaction between the syllabic pattern and the clinical condition showed no significant difference ($F=0.61$, $df=1.7$, $p=0.43$). The descriptive values (Table 2) and boxplot (Figure 4) show that the ratio between the tip and the blade of the tongue is higher in the syllable whose target is the CCV structure if compared to what occurs in the target syllable with a CV structure ($p <0.05$).

Figure 4 – Box plot of the ratio between tip and blade of the tongue of the typical and atypical children in two syllabic patterns (CV in blue and CCV in green). The x-axis represents the clinical condition of the subjects and the y-axis are found the values (in percentage) of the ratio between the tip and the blade of the tongue.

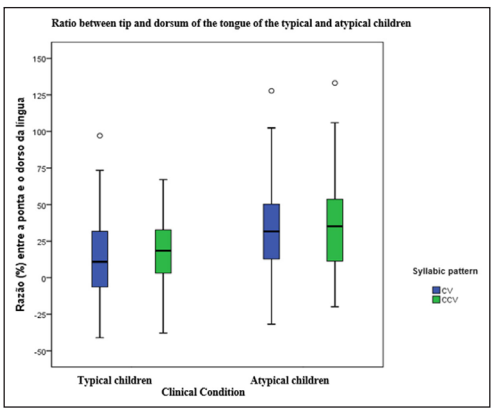


Source: author's elaboration

For the ratio between the tip and dorsum of the tongue, the repeated measures ANOVA showed effect to the syllable pattern (F=9.81, df=1.7, p=0.00) and for the clinical condition (F=13.99, df=1.7, p=0.00). The interaction between the syllabic pattern and clinical condition showed no significant difference (F=1.07, df=1.7, p=0.30). Through an inspection of the descriptive values (Table 2) and the boxplot (Figure 5), it is possible to verify that the CCV target structure presents a greater ratio between the tip and dorsum of the tongue when compared to the CV, that is, children, regardless of the clinical condition, present a higher elevation of the dorsum during the production of the CCV target.

In addition, when comparing the clinical condition of the children, it was possible to identify that the TT/DT ratio is lower in typical children compared to the values obtained for atypical children, that is, atypical children present a higher elevation of dorsum when compared to children with expected phonological development, as can be seen in Figure 5.

Figure 5 – Box plot of the ratio between tip and dorsum of the tongue of the typical and atypical children in two syllabic patterns (CV in blue and CCV in green). The x-axis represents the clinical condition of the subjects and in the y-axis are found the values (in percentage) of the ratio between the tip and the dorsum of the tongue.

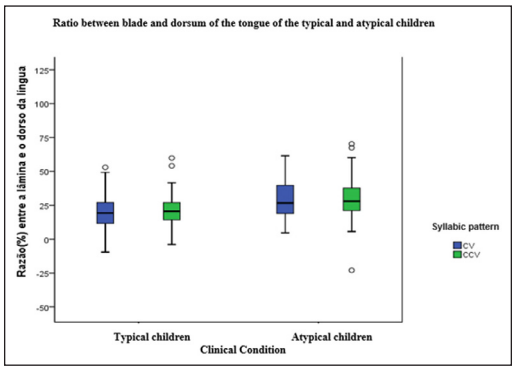


Source: author's elaboration

The repeated measures ANOVA showed a significant effect for the syllable pattern (F=4.54, df=1.7 p=0.03) for the clinical condition (F=35.6, df=1.7, p=0.00) and for the measure of the ratio between the blade and the dorsum of the tongue; the interaction between the syllabic pattern and clinical condition showed no significant difference (F=0.61, df=1.7, p=0.43). When analyzing the descriptive values and boxplot (Figure 6) comparing the clinical condition of the children, it was possible to identify that the BT/DT ratio is lower in typical children compared to the values obtained for atypical children, that is, atypical children present a higher elevation of the dorsum with respect

to the blade of the tongue when compared to the children with typical phonological development.

Figure 6 – Box plot of the ratio between blade and dorsum of the tongue of the typical and atypical children in two syllabic patterns (CV in blue and CCV in green). The x-axis represents the clinical condition of the subjects and the y-axis are found the values (in percentage) of the ratio between the blade and dorsum of the tongue.



Source: author's elaboration

Discussion

As previously explained in the introduction of the present paper, the purpose of this study was to characterize the production of target words with CCV versus CV syllabic patterns in children with typical and atypical phonological development. The first hypothesis (H1) - that children with typical production would present different ultrasound and acoustic measures in the comparison of the target production with the CCV and CV syllables - was confirmed integrally by all measures: ratio between TT/BT, TT/DT and BT/DT, in addition to the measure of relative duration.

The fact that the mean value of the ratio between TT/BT relative to the CCV target (-2.00%) has been higher than the mean value for the CV target (-5.56%) means that there was a higher elevation of blade of the tongue during the clusters production as a target. Likewise, for TT/DT, the mean values of the ratios in the CCV syllable were 18.23% and 13.58% for CV. Finally, for the BT/DT ratio, the mean values of the ratios in the CCV target syllable were 20.94% and for the CV target syllable were 19.9%.

Thus, the joint analysis of the ratios between TT/BT, TT/DT and BT/DT during the production of CCV targets in typical children indicates evidence that there is blade and tip of the tongue elevation simultaneously during the production of CCV.

In relation to the duration measure, the CCV target syllables also presented higher measures (54%) to the mean values of the CV ratios (50%) for the group of typical children and for the group of atypical children (49% and 46%), suggesting differentiation in terms of the syllabic pattern for both groups of children.

The object of study reported here is associated with CCV target structure, where tap is at the C2 position. Therefore, we appealed to the acoustic-articulatory characterizations already described in the literature, even though they describe tap in the CV target structure. Albano (2001), Silva (2003) and Silva, Clemente and Nishida (2006) describe that, in Brazilian Portuguese (BP), the rhotics, as in the case of rhotic liquid, have a double gestural specification in different acoustic-articulatory regions. Studies involving the phonic production of adults point to the presence of the bigestuality composed of two simultaneous oral gestures: one related to the coronal region and the other related to the dorso-pharyngeal region.

A study involving ultrasound and dynamic analysis of the liquid production in the Malayalam language (a language spoken in the state of Kerala in southern India) has also identified, specifically for the rhotic, a progress of the root of the tongue along with an independent tongue elevation toward the palate, resulting in two simultaneous gestures during the production of /ɾ/ (SCOBBIE; PUNNOOSE; KHATTAB, 2013).

Berti (2010) analyzed, by means of ultrasound images of the tongue, the production of the liquids /ɾ/ and /l/ inserted in the CV target syllable of BP produced by an adult and identified the presence of two simultaneous articulatory gestures: a gesture of the tip of the tongue and a gesture of the body of the tongue. The presence of two gestures may thus present greater difficulty in coordinating tongue movements. Another Brazilian study (BARBERENA; KESKE-SOARES; BERTI, 2014) also used ultrasound data to investigate /ɾ/ and /l/ segments in the speech of adult speakers of BP and found that both /ɾ/ and /l/ present two simultaneous gestures: tip and body of the tongue, confirming the acoustic descriptions of Silva (2003) and the ultrasound findings of Berti (2010). In addition, the authors showed that the vowel context of /i/ favors a higher degree of constriction to the tip of the tongue when compared to the other vowel contexts.

Children with typical development seem to be in the direction of the target production, that is, looking for the phonic production similar to the adult, since during the production of CCV targets, there is a higher elevation of the tip of the tongue when compared to the CV syllable. The ratio between the tip and the dorsum of the tongue show that they show elevation of the tip of the tongue in 18.23% in the CCV target syllables, while in the CV syllable it is 13.58%.

The hypothesis (H2) postulates that the ultrasound measures could differentiate children's clinical condition. Of the four articulatory measures analyzed, two were able to differentiate the children's clinical condition: the measures of the ratio between TT/DT and BT/DT. For all measures, atypical children's productions presented higher values compared to the typical children's productions (see Table 1), indicating a greater use of the tongue in the syllable productions analyzed for atypical children.

The study of Gick et al. (2007), which analyzed phonological substitution processes involving English liquids in syllabic patterns with CV target, concluded that, in order to acquire /ɾ/ or /l/, it is necessary to coordinate refined dissociated movements of the tongue (tip and body of the tongue), in addition to being simultaneous. Due to the

multiple constrictions of the tongue, associated with anatomical limitations in children (large tongue and a small pharyngeal cavity), liquids tend to be acquired later.

Although children had similar anatomical structures in terms of the tract size, regardless of the clinical condition, it was possible to verify differences in the gesture coordination of /r/ among the groups of children. The explanatory hypothesis for the difference in the production of typical and atypical children may be associated with the presence of undifferentiated gestures (GIBBON, 1999a, 1999b) in the speech production of atypical children. The GIs manifest when the tongue comes in contact simultaneously with the anterior and posterior region of the palate or when the entire surface of the tongue comes into contact with the palate, and there is a lack of distinction between the gestures of the tip of the tongue and body of the tongue and the lateral margins of the tongue against the palate (GIBBON, 1999a).

In speech production of children with expected development, the tip of the tongue and body of the tongue are almost independent articulators, being able to produce well defined patterns against the palate. However, when they present the GIs, children are unable to differentiate gestures between the tip and the anterior body of the tongue. The GIs can be interpreted as indications of motor speech restriction present due to delays or deviations in the control of these regions of the tongue (GIBBON, 1999b).

Possibly, the children with atypical productions for the CCV syllables have GIs, keeping the tongue closer to the palate, which explains the greater ratio between TT/DT and BT/DT compared to the values presented by typical children, as the results of this study pointed out.

In a study involving electropalatography, Goozée et al. (2007) identified with undifferentiated gestures an excessive movement of body of the tongue during the production of the consonant /t/. In this study, the atypical children do not seem to coordinate the gesture of tip and body of the tongue during CCV production, which can be interpreted as a greater use of tongue as a result of GIs. The authors believe that such excessive movement of the body of the tongue may take place from poor, immature or deviant motor control to the lever system and/or the compensation mechanism to neutralize the fine motor control disorders of the tip of the tongue. The results of this research, especially the measure of the ratio between TT/DT, corroborate the finding of Goozée et al. (2007).

The hypothesis (H3) maintains that children with atypical production could present differences in ultrasound measures in the comparison of the production of target CCV and CV syllables, although CCV has been aurally judged as CV. According to Gestural Phonology, it is possible to record the presence of articulatory gestures of reduced magnitude or overlapping, even in productions aurally judged as simplified. Then, it was expected to find some difference in the articulatory and acoustic measures between the CCV and CV targets in the production of children with atypical phonological development.

As the measure of relative duration differentiated the syllabic pattern (CCV versus CV target), regardless of the subjects' clinical condition, it is verified that, in the group

of studied children, both typical and atypical, there is no gestural overlapping, since the longer duration for the CCV target is maintained.

Among the three ultrasound measurements used, two were able to differentiate the syllabic pattern and the clinical condition of the children. The measures of ratios between TT/DT and BT/DT differentiated the CCV and CV target syllables performed by the two groups of children. Specifically, in the group of children with atypical phonological development, the mean value of the TT/DT ratio for the CCV target was higher than the mean value obtained for the CV target, suggesting that atypical children raise the tip of the tongue; however, due to the reduced magnitude of the gesture, the ear does not detect the rhotic, which, consequently, confirms the presence of hidden contrasts in the speech of atypical children.

Although the literature has not reported Brazilian ultrasound studies that compare the CCV targets with CV targets in children with typical and atypical phonological development, it is possible to rely on previous research (MIRANDA; SILVA, 2011; MEZZOMO; MOTA; GIACCHINI, 2008), which analyzed the production of CCV and CV by means of acoustic data and identified the presence of compensatory stretching strategies of the vowel (EAC) to differentiate CCV from CV. In the attempt to establish phonological contrasts in the language, children with atypical phonological development make use of repair strategies in order to adapt the production to the target system. In this case, the use of vowel stretching in CCV syllables indicates the categorization of CCV and CV syllabic patterns differently from that expected by the speech community.

The presence of EAC is interpreted by the authors as a reparative strategy for those children who still do not produce the complex onset adequately, but have a previous phonological knowledge in respect of the syllabic structure (MEZZOMO; MOTA; GIACCHINI, 2008; MIRANDA; SILVA, 2011; GIACCHINI; MOTA; MEZZOMO, 2011). This means that these children have phonological knowledge of the CCV structure, but cannot produce it solely for motor reasons (MEZZOMO; MOTA; GIACCHINI, 2008).

It is believed that the motor difficulties described by Mezzomo, Mota and Giacchini (2008) and corroborated in this research may be due to undifferentiated gestures present in the tongue of the deviant children, as previously explained.

The acoustic data of this study corroborate the previously mentioned studies, since the relative duration was able to differentiate the CCV target syllables from the CV target syllables, although it was not able to segregate the clinical condition of the studied children. The explanation of the Gestural Phonology for the differentiation of the syllabic patterns, from the temporal point of view, occurs in the gesture coordination present in these syllables.

As previously mentioned, the gestures coordination is due to the phasing relation between the gestures present within the syllable, in this case, in CV and CCV. For the CV syllable, the consonant and vowel gestures are coordinated in phase, that is, the C and V gestures are activated simultaneously. In the case of syllables of the CCV type, two types of gestural coordination are present: in phase and in antiphase. The

gestures related to the consonants establish an antiphase relation between them, while both consonants are in phase with the vowel. The antiphase relation between CCV consonants is necessary in order to achieve the distinctiveness between consonantal gestures (BROWMAN; GOLDSTEIN, 2000; MARIN; POUPLIER, 2010). In temporal terms, the CCV target syllable presented longer duration than CV, since in the first case, activation and coordination of three/four simultaneous gestures (depending on C1)[7] are necessary, which would take more time, that is, regardless of the clinical condition, children seek to achieve the contrast between CCV and CV.

Thus, the results, taken together, partially confirm the hypotheses assumed, since the ultrasound measurements analyzed differentiated the CV and CCV syllabic production in typical and atypical children (TT/BT, TT/DT and BT/DT). In addition, some of the ultrasound measurements (ratios between TT/DT and BT/DT) differentiated the clinical condition of the subjects (typical children from atypical ones). The acoustic measure (relative duration) was able to differentiate the syllabic pattern (CCV from CV), independently of the clinical condition of the children.

The atypical children seem to still be "in the middle of the way" reaching the target production; apparently, they are at an even more immature stage in terms of motor maturation whether compared to typical children. In relation to the structure of the vocal apparatus, the children have a voluminous tongue and a small pharyngeal cavity, which would make it difficult for the simultaneous multiple constrictions of the tongue, necessary for the production of /ɾ/, which may be manifested as the second consonant of the CCV sequence. However, the children classified as atypical would have motor restrictions that prevent the gestures of the tip and the body of the tongue from dissociating and occurring simultaneously.

Conclusions

This study characterized the production of target words with syllabic patterns of CCV versus CV types in children with typical and atypical phonological development. For this purpose, the instrument to measure the gestures involved in syllabic patterns was ultrasonography, which is able to simultaneously and synchronously capture speech sound and images of the tongue contour.

Of the ultrasound measures used, the distances involving the ratios between TT/BT, TT/DT, and BT/DT were sensitive to differentiate the production of CCV and CV in typical and atypical children's productions. The clinical condition of the children was differentiated by the measures of the ratios (TT/DT and BT/DT), and the CCV and CV syllables produced by atypical children, even if CCV has been judged as CV, in perceptive analysis, they were differentiated by the ratios between TT/DT and BT/DT.

[7] In the case of the phoneme /b/, for example, three gestures are activated: lips, velum for the closure of the oronasal cavity and laryngeal to perform the vocal fold vibration.

The articulatory results suggest the presence of tip of the tongue elevation to produce the rhotic (which is positioned in the C2 of the CCV target structure) with reduced magnitude, and the acoustic findings suggest the non-overlapping of the gestures in the production of CCV. Additionally, in the group of atypical children, the results reveal the presence of undissociated gestures in the production of target words with CCV syllabic structure.

The results show that atypical children produce the CCV and CV target syllables differently from the group of typical children, which can be elucidated by the presence of undissociated gestures in the production of the CCV target. The atypical children seem to present GIs, because the ultrasound measures indicate that this group has restrictions in differentiating the tip of tongue gestures and the anterior body of the tongue. The GIs may be associated with motor speech restrictions, present as a result of delays or deviations in the control of these regions of the tongue in the group of children with difficulties in the production of target words with the CCV structure.

We intend, in the future, to investigate the presence of undissociated gestures in other segments of the BP, as already identified in other languages. If present, it will be investigated to what extent the motor and/or symbolic aspect is influencing in the uncoordinated patterns of the language. Therefore, the use of ultrasonography will become indispensable for the study of the infantile speech production. This will aid in the understanding of how atypical children perceive phonological contrasts, especially in relation to syllabic patterns.

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- *RESUMO: O objetivo principal deste estudo é caracterizar a produção de palavras com as sílabas-alvo do tipo CCV e CV em crianças com desenvolvimento fonológico típico e atípico. As hipóteses foram: H1 - a produção de palavras-alvo com sílaba CV e CCV das crianças típicas apresentariam diferentes medidas ultrassonográficas e acústica; H2 - as medidas ultrassonográficas e acústica poderiam diferenciar a condição clínica das crianças; H3 - as*

crianças com produção atípica poderiam apresentar diferenças nas medidas ultrassonográficas e acústica entre os alvos CCV (sendo o tepe na posição de C2) e CV (CCV julgadas auditivamente como CV). Dez crianças gravaram palavras com as sílabas-alvo CCV e CV. Em seguida, foram feitas análise de oitiva, análise acústica e ultrassonográficas (razões entre ponta e lâmina da língua (PL/LL), ponta e dorso da língua (PL/DL), e a lâmina e dorso da língua (LL/DL)), sendo analisadas pela ANOVA de medidas repetidas. A H1 foi corroborada pelas razões entre PL/LL, PL/DL e LL/DL, indicando que as crianças típicas produzem maior elevação de ponta e lâmina de língua na sílaba-alvo CCV se comparado à sílaba-alvo CV. As H2 e H3 foram parcialmente confirmadas pelas razões entre PL/DL e LL/DL e entre PL/DL e LL/DL, respectivamente. Os resultados sugerem que as crianças com desenvolvimento típico parecem estar em direção da produção-alvo, já que, em CCV, ocorre maior elevação da PL e de duração se comparado à sílaba CV. Para as crianças atípicas, as razões entre a PL/DL mostram que têm elevação de ponta de língua em 18,23% nas sílabas-alvo CCV, enquanto na sílaba-alvo CV é de 13,58%, sugerindo a presença de elevação da PL para produzir o tepe com magnitude reduzida e a não sobreposição dos gestos do alvo CCV, bem como gestos indiferenciados.

- *PALAVRAS-CHAVE: Análise Articulatória. Aquisição da linguagem. Fonética acústica. Português brasileiro.*

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