TONGUE MOVEMENT IN CONSONANT CLUSTER REDUCTION IN BRAZILIAN CHILDREN WITH PHONOLOGICAL DISORDER: DURATION AND TONGUE DISPLACEMENT MEASURES

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▪ ABSTRACT: This study characterized tongue displacement and duration measures in phonological disorder and typical children´s productions of Brazilian Portuguese speakers. The hypotheses are: (1) children with phonological disorder are characterized by longer duration than typical children; and (2) tongue displacement is greater in phonological disorder and typical children´s productions. Participants were five children diagnosed with phonological disorders (PD) and five typically developed (TD). The corpus consisted of three repetitions with two syllable patterns: CCV and CV. The images were captured simultaneously by the Articulate Assistant Advanced software. The hypothesis 1 was not confirmed and hypothesis 2 was partially confirmed. The durational measures demonstrated that the CCV syllables were significantly longer than the CV syllables in TD. The posterior and average tongue displacement is greater in phonological disorder. The children with phonological disorders do not seem to coordinate gestures of the tongue tip and dorsum during CCV production separately (expected for the production of tap), however they displaced the average and posterior region of the tongue.

▪ KEYWORDS: articulatory analysis; language acquisition; phonological acquisition; brazilian portuguese.

Introduction

Ultrasound has established itself as a useful new speech analysis technique, in particular for studying and therapy of tongue movement in speech disorders (BRESSMANN HENG; IRISH, 2005; CLELAND; SCOBBIE; WRENCH, 2015; BACSFALVI; BERNHARDT, 2011; CLELAND *et al*., 2016). A particular area of

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interest has been the analysis of complex tongue gestures, such as the production of consonant clusters, as well as the consonant cluster reductions observed in children with atypical speech development (ALBANO, 2001; BACSFALVI; BERNHARDT, 2011; ZHARKOVA; GIBBON; LEE, 2017).

Consonant clusters (CCV) are challenging to acquire for children with phonological disorder. Acoustic research by Miranda and Silva (2011) and Mezzomo, Mota and Giacchini (2008) has investigated differences between the production of consonant clusters by children with typical and with phonological disorder. The results by Miranda and Silva (2011) demonstrated longer duration of CCV syllables produced by children with phonological disorder compared to those produced by typically developing children. These results were interpreted as an indication that children with phonological disorder used the lengthening to distinguish between their CCV and CV productions, which are typically perceived as CV by listeners. This shows that children with phonological disorder have some abstract phonological knowledge about syllable structures.

Mezzomo, Mota and Giacchini (2008) also through acoustic cues identified the use of the compensatory stretching strategy between phonological disorders and typically developing children during the production of consonant cluster. The instrument analysis was able to validate the phonological knowledge in relation to the presence of the consonant cluster when it is not yet filled with the target segments, indicating to the need for the use of spectrography to perform more reliable phonological descriptions.

Based on ultrasound and magnetic resonance data, Gick *et al.* (2007) described articulatory differences in liquid substitutions in children with phonological disorder. The authors argued that segmental errors, such as [w] for [r], are the result of reduced lingual degrees of freedom. With another articulation analysis instrument, Lee *et al.* (2014) used electropalatography to investigate the production of vowels in children with typical and with phonological disorder. They found more extensive linguopalatal contact patterns in children with phonological disorder, indicating poorer temporal and spatial control of tongue movements.

Previous ultrasound research on consonant cluster reduction in typical developing speakers of Brazilian Portuguese (BP) (VASSOLER; BERTI, 2018; OLIVEIRA; BERTI, 2018) revealed differences between the tongue movements and reduced consonant clusters involving rhotic sounds. When comparing the production of target sounds [ɾ] e [l] in the CV syllable pattern through overlapping of tongue contours, Barberena (2016) analyzed the production of children with typical phonological development, phonological disorder and adults. The author verified that during the production of [l], groups of typical children and with phonological disorder showed a statistical difference between the means of standard deviations of the tongue contours, in the same way as in the production of [ɾ], there was also a difference between the two groups for the context of the vowel /a/. In addition, it was observed for the group of children with phonological disorder, both target sounds [ɾ] and [l] showing two distinct gestures (tongue tip and root), and it differs from each other, since in [ɾ] there was greater retraction of the root towards the pharynx and greater elevation of the tongue tip and dorsum compared to

[l]. As more constriction of the tongue tip and root is necessary to achieve the expected acoustic results for /ɾ/, phonological disorder tends to perform the sounds [l], [j] or even the omission of the target sound (/ɾ/), due to the difficulty of dissociating double articulatory gestures in a single oral articulator.

Berti, Boer and Bressmann (2016) compared the productions of children with typical phonological development and phonological disorder, using the tongue displacement measure during the production of liquids (/l/, /ʎ/, /ɾ/ and /ʁ/ in the context of vowel /a/). The results showed that children with phonological disorder performed greater tongue displacement in the production of /l/ and /ʎ/, compared to typical children. The authors interpreted this result as lack of anatomical control of the tongue during the production of the involved segments (corroborating an earlier study by Gibbon (1999).

Concerning the production of liquids inside of syllabic pattern as C(ɾ)V, Vassoler and Berti (2018) analyzed the typical production and phonological disorder of both CV and CCV in which the second C corresponds to [ɾ], by measuring the area between the tongue tip and blade at the maximum constriction point of the tap. The authors identified that children with phonological disorder presented, in both syllable patterns (CCV and CV), higher area values between tongue tip and blade compared to typical children, thus indicating that children with phonological disorder use a larger area of the tongue, and possibly do not differentiate the tip and anterior body gestures of the tongue in the production of CV and CCV.

In another study, Oliveira and Berti (2018) also investigated the typical production and phonological disorder CV and CCV through measures of ratios between tongue tip and blade, tongue tip and dorsum and tongue blade and dorsum. The positive ratio value between tongue tip and blade means that the tip of the tongue is in a higher position when compared to the blade, whereas the negative value of the relation means that the tongue tip is lower than the blade. The results suggest that children with typical development seem to be in the direction of the CCV syllable pattern expected (higher elevation of tip) when compared to the CV syllable. For children with phonological disorder, ratios showed the elevation of tongue tip for both syllables, suggesting the presence of tongue tip elevation to produce the tap sound with reduced magnitude and non-overlapping gestures of the CCV target (undifferentiated gestures).

The studies (VASSOLER; BERTI, 2018; OLIVEIRA; BERTI, 2018) showed that higher area and elevation in the anterior region of the tongue in the speech of children with phonological disorder can be compared to the ones in the speech of typical children. Research involving liquids CV target syllabic (BERTI; BOER; BRESSMANN, 2016; BARBERENA, 2016; VASSOLER; BERTI, 2018) has indicated that children with phonological disorder have greater tongue displacement that can be marked by a longer duration.

Thus, it is possible to verify that quantitative ultrasound analysis has contributed to differentiate the typical productions of phonological disorder in different sounds and syllable patterns. Literature has already pointed out that quantitative ultrasound measurements are able to differentiate groups of children (typical and children with

phonological disorder) during the production of liquids both in CV (BARBERENA, 2016) and CCV (VASSOLER; BERTI, 2018) target syllabic. Thus, regarding all the previously analyzed measures, it can be inferred that there is a higher elevation of the anterior region of the tongue during the production of CCV in cases of children with phonological disorder.

However, previous studies have not showed information about the tongue displacement during the production of this syllable pattern. Based on the literature (VASSOLER; BERTI, 2018; OLIVEIRA; BERTI 2018) that children show greater use of the tongue mass in atypical productions, resulting in a greater tongue displacement and in a longer duration, this research intends to corroborate/refute these previous findings, from the following hypotheses:

(1) In BP, children with phonological disorder are characterized by longer durations than typical children;
(2) The tongue displacement is greater in the productions of phonological disorder children than in typical children.

Thus, this study aimed to characterize the displacement in phonological disorder and typical children´s productions in BP.

Materials and methods

Participants

A total of 10 participants, speakers of BP, took part in the study: 5 children with typical development and 5 children with phonological disorders (i.e., presenting exclusively reduction of consonant clusters). For both groups of children, the exclusion criteria were: absence of intellectual and neurological disorders; absence of anatomical and morphological alterations, which impaired speech production process (e.g., cleft lip and palate); and absence of otology/ hearing disorders.

Procedures or equipment

Participants were recorded individually in a single session of approximately 30 minutes, in the Acoustic Analysis Laboratory - LAAC UNESP campus of Marília (São Paulo, Brazil).

These recordings were performed with the use of a portable ultrasound device (Mindray 6600 model), located in an acoustically treated room. Ultrasound images were acquired with a 6.5 MHz image frequency and a 120° view angle. The ultrasound machine produced an NTSC video feed with a 29.97 Hz frame rate. The ultrasound

transducer was stabilized using the Probe Stabilization Headset (Articulate Instruments, Edinburgh, UK). Sound was recorded using a Shure model 8800 cardioid dynamic microphone (Shure Inc., Niles, IL, USA).

The ultrasound image and the sound signal were recorded directly to the hard disk of a personal computer. The Articulate Assistant Advanced software (AAA - Articulate Instruments, Edinburgh, UK) was used for the ultrasound and sound recordings. The software also synchronized the video and audio recordings.

Stimuli

This study focused on to analyze the production of tap within consonant clusters in onset (CɾV) versus simple onset (CV). The children recorded a corpus with 9 pairs of words containing the syllabic pattern CCV and CV: broa [ˊbɾoɐ] (‘bread’); boa [ˊboɐ] (‘good’); prato [ˊpɾatʊ] (‘dish’); pato [ˊpatʊ] (‘duck’); prego [ˊpɾɛgʊ] (‘nail’); pego [ˊpɛgʊ] (‘I pick up’); pressa [ˊpɾɛsɐ] (‘hurry’); peça [ˊpɛsɐ] (‘piece’); bruxa [ˊbɾuʃɐ] (‘witch’); bucha [ˊbuʃɐ] (‘bushing’); troco [ˊtɾokʊ] (‘change’); toco [ˊtokʊ] (‘tape’); grato [ˊgɾatʊ] (‘grateful’); gato [ˊgatʊ] (‘cat’); frita [ˊfɾitɐ] (‘fried’); fita [ˊfitɐ] (‘ribbon’). The criterion of the chosen words was to contain the syllabic pair CCV and CV, obeying the criteria of high lexical frequency in BP (MIRANDA; SILVA, 2011).

The figures referring to the minimum pairs were presented to the individuals by means of a playful activity, that is, the child visualized the corresponding image on the AAA screen and produced the target word. The identification of some target words “grato [ˊgɾatʊ], pego[ˊpɛgʊ] and boa” [ˊboɐ] [verb and adjective] were mentioned by the evaluator before beginning the recording. If the child produced a divergent from the expected word, the researcher would request an imitation of the target word.

For each word, the individuals were requested to produce five repetitions, and the three best recordings were used with respect to the image quality. Both pictures and audio prompts were given to the children. The number of total recorded stimuli was: 540 (3 repetitions x 18 words x 5 children with phonological disorder + 5 typical children).

Auditory-perceptual analysis

The sound recordings of the syllables were exported from the Articulate Assistant Advanced software. Three speech therapists with experienc in phonetic transcription provide auditory perceptual judgment (judges in the same dialectal area of the participants). The 540 stimuli were randomly arranged, in an attempt to avoid response patterns in the trial. The judge had three choices and selected between CCV, CV or other option (in this case it would be necessary to transcribe).

Duration measures

The sound files were edited and catalogued in AAA software, then exported and analyzed by PRAAT software (BOERSMA; WEENINK, 2014). The acoustic parameters used in the analysis were: the absolute duration of CCV and CV syllables and the relative syllable duration of the analyzed syllabic pairs. Segmentation was based on the duration measurement between the acoustic record of the plosive (in the burst) or fricative (in the fricative noise) consonant until the end of the subsequent vowel.

Ultrasound measures

A total of 540 ultrasound videos (10 participants × 3 repetitions × 18 words) were segmented using the AAA software. The video ultrasounds were identified and the tongue surfaces in the identified frames were traced semi-manually using the AAA.

In CCV syllable, the frame corresponding to the highest elevation of the tongue for the tap and the frame corresponding to the center of the following vowel were identified. Similarly, in the CV syllable, the frame corresponding to the highest elevation of the tongue between the consonant and the vowel (where the tap would be) and the frame corresponding to the center of the following vowel were identified.

The tongue heights (in millimeters) were made along 42 equally-spaced radial lines forming 120 degrees. The chosen confidence threshold was 90% and the values below it were excluded due the poor quality of tongue surface.

The analysis was based on previous study (BERTI; BOER; BRESSMANN, 2016). Data from the 28 center grid lines (between 8 and 35 grid lines) were considered because the more anterior or posterior measurement lines did not contain data. The authors developed a global measure of tongue displacement to compare the tongues of different speakers. The displacement measure was calculated as a percentage by dividing the tongue height values along the measurement grid lines for the tap in CCV (or between consonant and vowel, in CV) by the tongue height values for the following vowel.

The displacement was calculated by averaging the absolute percentage at the different measurement points between 8 right and 35 left. All cells that contained divisions of or by 0 were removed. Similarly, the anterior half (8 and 17 grid lines) and posterior half (17 and 35 grid lines) of the tongue percentage displacement measures were also calculated.

Statistical approach

For the analysis, the Statistical Package for the Social Sciences (SPSS, IBM) was used. The acoustic and articulatory measures were analyzed with separate two-way repeated measures ANOVAs. The syllabic patterns as inter-subject variables (CV and

CCV syllable) and as intra-subject variables, the clinical condition (typically developing vs. developmental phonological disorder).

For the repeated measures–ANOVAs, p values were considered significant if they were lower than .05 with Bonferroni test.

Results

Measurement

Auditory-perceptual analysis

From 270 words whose onset is formed by CCV, 135 (100%) of the productions of the CCV target-structure performed by children with typical phonological development were assessed, in the perceptual-auditory analysis, as a CCV target, while 135 (100%) of the productions of this target structure by children with phonological disorder were assessed as CV.

From 270 target words with CV onset, 135 (100%) of the productions CV target-structure performed by children with typical phonological development were judged as CV and from 135 (100%) of the productions of that target-structure by children with phonological disorder were assessed as CV.

Absolute duration

Summaries of the results for the absolute duration of the CCV and CV syllables are shown in Table 1:

Table 1 – Characterization of the children that participated in the investigation.

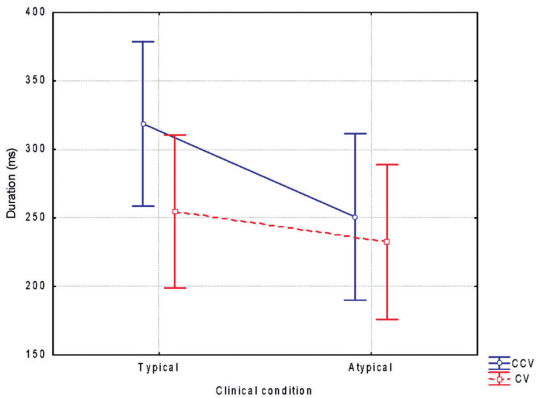
Clinical Condition	Children	Gender	Age
Typical development	1	Female	5 years and 4 months
Typical development	2	Female	6 years and 8 months
Typical development	3	Female	5 years and 6 months
Typical development	4	Male	6 years and 3 months
Typical development	5	Female	6 years and 2 months
Phonological disorder	6	Female	6 years and 0 months
Phonological disorder	7	Male	6 yearss and 9 months
Phonological disorder	8	Male	6 years and 7 months
Phonological disorder	9	Male	5 years and 5 months
Phonological disorder	10	Female	5 months and 5 months

Source: Author's elaboration.

Repeated measures ANOVAs were calculated for the absolute duration. A significant within-subject effect was found for syllable pattern (F=40.6, df=1.87, p<0.00) and there was no significant effect for group (typically developing vs. developmental phonological disorder) (F=3.81, df=1.87, p=0.05).

The interaction between group and the approached syllable pattern was statistically significant (F=12.50, df=1.87, p<0.00). Post-hoc testing with Bonferroni's tests demonstrated that CCV syllables were significantly longer than CV syllables (p<0.00) in typically developing ´s production. Figure 1 shows the duration of the CCV and CV syllables in the two groups of children:

Figure 1 – Duration of thetarget CCV and CV by groups.



Source: Author's elaboration.

Tongue displacement

Summaries of the results for means and standard deviations for the average, anterior and posterior displacements are shown in Table 2:

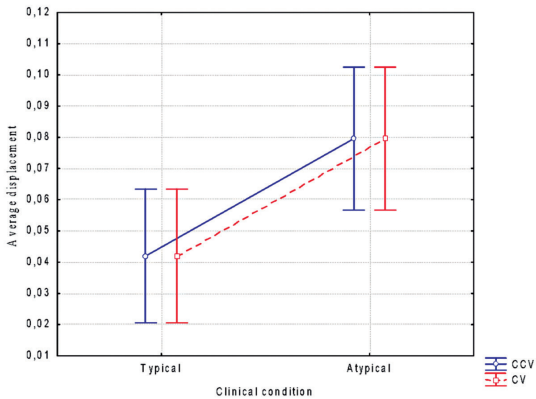
Table 2 – Target syllable duration of the CCV and CV syllable of typical and atypical children.

Clinical condition	Absolute duration	
	CCV	CV
typically developing	318.62(118.63)	254.55(111.79)
phonological disorder	249.43(124.74)	231.14(112.91)

Source: Author's elaboration.

For the average displacement, repeated measures ANOVA demonstrated a significant within-subject effect for clinical condition (F=17.37, df=1.57, p<0.00) and the test does not show a within-subject effect for the syllable pattern (F=65.14, df=1.57, p=1.00). The interaction between group and syllable pattern was not statistically significant (F=12.21, df=1.5, p=1.00). Post-hoc testing with Bonferroni's tests demonstrated that phonological disorder´s productions were significantly greater in tongue displacement than typically developing´s production (p<0.00). Figure 2 shows the average displacement by target CCV and CV:

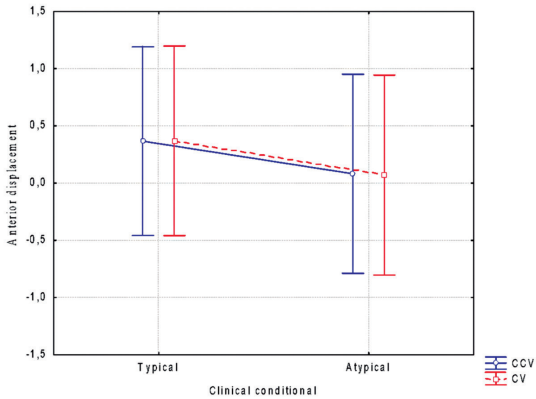
Figure 2 – Box-plot for average displacement by target CCV and CV.



Source: Author's elaboration.

For the anterior displacement, a repeated measures ANOVA does not show a within-subject effect for the syllable pattern (F=0.63, df=1.6, p=0.43) and there were no between-subjects differences for the speaker groups (F=0.64, df=1.58, p=0.42). The interaction between group and syllabic pattern was not statistically significant (F=1.31, df=1.58, p=0.25). Figure 3 shows the anterior displacement of the CCV and CV syllables in the two groups of children:

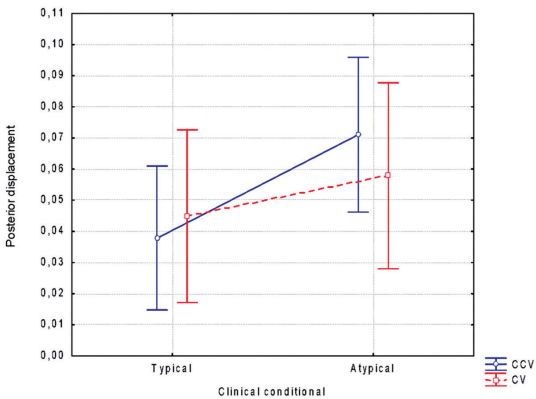
Figure 3 – Box-plot for anterior displacement by target CCV and CV.



Source: Author's elaboration.

Regarding the posterior displacement, the repeated measures ANOVA demonstrated a significant between-subjects clinical conduction effect (phonological disorder and typical children) (F=6.00, df=1.62, p=0.01), but there were no within-subject effect found for syllable pattern (F=0.32, df=1.62, p=0.56). The interaction between group and syllable pattern was not statistically significant (F=3.58, df=1.62, p=0.06). Figure 4 illustrates the posterior displacement by target CCV and CV:

Figure 4 – Box-plot for posterior displacement by target CCV and CV.



Source: Author's elaboration.

Discussion

The goal of the present study was to characterize the production of children with typical and with phonological disorders in BP. The research hypotheses were that (i) the children with phonological disorder are characterized by longer durations than typical language development (first hypothesis); and (ii) the tongue displacement is greater in phonological disorder than in typical children´s productions (second hypothesis).

According to the first hypothesis, it was expected that children with phonological disorder be characterized by longer durations than typical children. The hypothesis has not been confirmed.

The duration measures demonstrated that the CCV syllables were significantly longer than the CV syllables in typically developing, confirming previous results (EDWARDS *et al.,* 1999). Contrarily, other studies (MEZZOMO; MOTA; GIACCHINI, 2008; MIRANDA; SILVA 2011; GIACCHINI; MOTA; MEZZOMO, 2011) identified longer duration in the productions of children with phonological disorder. Although there was no statistical difference between the groups of children, they seem to have started the differentiation of the CCV and CV patterns, since numerically CCV syllables are longer than CV syllables. However, this difference was not robust enough to be statistically marked, as demonstrated by Oliveira and Berti (2018).

The second hypothesis is that the tongue displacement is greater in phonological disorder and typical children´s productions. This hypothesis was partially confirmed.

The average and posterior displacement values were different between the groups (typically developing vs. developmental phonological disorder). Children with phonological disorder showed greater displacement than productions of typical children. However, for the anterior displacement measures of the tongue, there was no difference between the groups, that is, the typical and atypical children's productions move the anterior region of the tongue in a similar way.

Although children have similar anatomical structures, regardless of clinical condition, it was possible to find differences in average percentage of the displacement of /ɾ/ between the two groups of children. A possible explanation for the difference in the production of typical and atypical children may be associated with the presence of undifferentiated lingual gestures (GIBBON, 1999; VASSOLER; BERTI, 2018; OLIVEIRA; BERTI, 2018), in speech production of atypical children. The undifferentiated lingual gestures are manifested when the tongue comes into contact simultaneously with the anterior and posterior regions of the palate, or when the whole tongue surface gets in contact with the palate, causing a lack of distinction between the tongue tip and dorsum and lateral margins of the tongue against the palate (GIBBON, 1999; VASSOLER; BERTI 2018), that is, children have difficulty distinguishing between coronal and dorsal tongue gestures, indicating again to a problem with the precise motor control needed for intelligible speech.

Gibbon (1999) conducted a thorough literature review article about undifferentiated gestures regarding studies involving electropalatography (EPG). Besides defining and

characterizing the term undifferentiated lingual gestures (UGs) (as mentioned in the previous paragraph), the author identified in the reported literature that, regarding 17 children with PD (or articulatory), 12 children with undifferentiated lingual gestures (not perceived by standard phonetic transcriptions) could be detected in EPG. The study indicated that the presence of UGs reflects difficulties in the motor (phonetic) level due to immature tongue control.

Another previous study (MCALLISTER, 2012), involving tongue ultrasound, *also* identified that children are known to have difficulty executing discrete tongue movements, preferring to move the tongue and jaw as a single unit. This predisposes the child to reduce undifferentiated linguopalatal contact, neutralizing the coronal-velar contrast (MCALLISTER, 2012).

Regarding the speech production of children with expected development, the tongue tip and tongue body are almost independent articulators, being able to produce well-defined standards against the palate. However, when children present the undifferentiated lingual gestures, they are unable to differentiate tip and anterior body gestures of the tongue. The undifferentiated lingual gestures can be understood as reflex of motor restrictions in speech, as a result of delays or deviations in control of these regions of the tongue (GIBBON, 1999).

In a study involving electropalatography, Gouzee *et al.* (2007) identified, in children with undifferentiated lingual gestures, excessive corpus of the tongue movement during the production of consonant /t/. The authors believe this excessive corpus of the movement may be the result of poor motor control, immature or deviant to the lever system and/or may be due to the compensation mechanism to neutralize the fine motor control disorders of the tongue tip. The results of this study corroborate Goozée *et al.* (2007)'s findings, that is, children with phonological disorders do not seem to coordinate gestures of the tongue tip and corpus during CCV production, which can be interpreted as a greater use of the tongue due to undifferentiated lingual gestures.

Conclusion

This study characterized the displacement in phonological disorder and typical children´s productions in BP. The ultrasound measurements involved the average, anterior and posterior tongue displacement measures during the production of CV and CCV syllables by children with phonological disorders and typically developing.

The durations of the CCV syllables are significantly longer than the CV syllables and the displacement of the tongue is different between typical and atypical productions of children. The average displacement of the tongue is greater in phonological disorders. Children with phonological disorders do not seem to coordinate the gestures of the tip and the dorsum of the tongue separately during the production of CCV, however they displace the tongue globally.

It can be observed that an ultrasound imaging is a useful tool for evaluating and characterizing typical and atypical speech production. The investigation of tongue movements during speech is highly recommended in order to observe speech errors, providing information for direct visualization of the articulators. It is a noninvasive, safe, fast and low-cost technique.

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OLIVEIRA, A.; BERTI, L. Contorno de língua de crianças brasileiras com desvio fonológico: medidas de duração e deslocamento da língua. **Alfa**, São Paulo, v.66, 2022.

- *RESUMO: Este estudo caracterizou as medidas de deslocamento e duração da língua no desvio fonológico na produção típica de crianças falantes do português brasileiro. As hipóteses são: (1) crianças com desvio fonológico caracterizam-se por uma duração maior que as crianças típicas; e (2) o deslocamento da língua é maior no desvio fonológico e nas produções típicas das crianças. Participaram cinco crianças com desvio fonológico e cinco com desenvolvimento típico de linguagem. O corpus consistiu em palavras contendo dois padrões silábicos: CCV e CV. As imagens foram capturadas simultaneamente pelo software Articulate Assistant Advanced (AAA). A hipótese 1 não foi confirmada e a 2 foi parcialmente confirmada. A duração é maior nas sílabas CCV. O deslocamento médio e posterior da língua é maior no desvio fonológico. As crianças com desvio fonológico parecem não coordenar os gestos da ponta da língua durante a produção de CCV (esperado para a produção do tepe), entretanto deslocam a região média e a região posterior da língua.*

- *PALAVRAS-CHAVE: análise articulatória; aquisição de linguagem; aquisição fonológica; português do Brasil.*

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