ACOUSTIC CHARACTERIZATION OF THE VOICING OF STOP PHONES IN BRAZILIAN PORTUGUESE

Caracterização acústica da sonoridade dos fones plosivos do português brasileiro

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ABSTRACT

Purpose: to investigate and compare the acoustic characteristics of voiceless and voiced plosives in the speech of children with typical phonological development and adults with typical language speech patterns. **Method:** the study's sample is arranged in two groups – 17 adults and 11 children with typical phonological development. Through words/pseudowords (*[ʻpapa], [ʻbaba], [ʻtata], [ʻdada], [ʻkaka]* and *[ʻgaga]*) inserted into carrier phrases (*"Say ___ papa again"*), the voice onset time, the length of the vowel, and we measured the burst amplitude and the length of the occlusion. The acoustic records of voiceless and voiced plosives intragroup and intergroup were compared through statistical tests ($p<0.05$). **Results:** in general, the results suggest that: (1) the voice onset time was longer for voiced plosives when compared to the voiceless plosives; (2) the vowel length when followed or preceded by a voiced plosive was longer than in front of a voiceless plosive; (3) the burst amplitude was slightly superior during the production of voiced segments and; (4) the length of the occlusion was superior in the context of voiceless plosives. Furthermore, the adults and children showed many similarities related to the production of these parameters. **Conclusion:** the investigated acoustic cues present themselves as strong parameters involved in the characterization of plosives voicing contrasts. Furthermore, the results also indicate many similarities among adults and children with typical phonological patterns. However, when some differences are evident, they occur on medial and unstressed syllables.

KEYWORDS: Speech Acoustics; Adult; Child; Sound Spectrography/analysis; Speech

INTRODUCTION

The typical phonological acquisition is a non-linear, gradual and intrinsic to the individual process, which ends with the establishment of a phonological system consistent with the adult target of the target language[1].

As regards the stop phonemes, its complete acquisition of the phonological system occurs around the age of two[1-3].

During the production of these segments, in a first moment, the phonoarticulatory organs form a total obstruction to the air passage, being the acoustic register an interval of silence, which can be filled by a prevoicing bar caused by the vibration of the vocal folds, as in the case of voiced stops ([b], [d] and [g]), which, distinctively, it is not observed for the voiceless stops ([p], [t] and [k]). After that, due to an increased intraoral pressure generated during the occlusion phase, there is a sudden release of the air stream, identified in the spectrogram as a brief transient noise, called *burst* [4].

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Conflict of interest: non-existent

From the acoustic point of view, some cues are described as responsible for the contrast in voicing of stops, such as voice onset time (VOT) [4,5], the length of the vowel adjacent to stop [4,6,7], the amplitude of the burst [4,5], the length of the previous occlusion release [6,8], among others.

Able to reflect the refinement and the coordination of glottic and supraglottic gestures involved in the production of stop phonemes, and also responsible for the contrast between the segments [+ voice], the VOT has been widely investigated in the literature [4,5,9]. An acoustic register is known as a measurement of length, which corresponds to the time interval between the release of the occlusion and the beginning of voicing (anterior, concurrent or posterior to burst) [4].

In the presence of voicing posterior to the release of the occlusion, the value of VOT is positive, characteristic of voiceless stop sounds. On the contrary, when the voicing is anterior or concomitant to burst, the VOT value is, respectively, negative or zero, characteristic of voiced stops [4].

Correlações acerca da duração da vogal no contexto de plosiva surda e sonora são também relatadas na literatura. Diante de um segmento plosivo sonoro, as vogais tendem a apresentar valores de duração superior àquelas vogais em contexto surdo [4, 6,7,9].

Correlations about the length of the vowel in the context of voiceless and voiced stop are also reported in the literature. Front to a stop sound segment, vowels tend to present higher length values if compared to those vowels in voiceless context [4, 6,7,9].

Another parameter used for the contrast identification of voicing of stops seems to be the amplitude of the burst. Authors state that this is more intense in voiceless consonant sounds in comparison to the voiced matching part.

Besides the acoustic registers which were already mentioned, the length of occlusion anterior to burst may be also responsible for the distinction of voiced and voiceless stops. However, its influence has been little investigated. In a research with speakers of European Portuguese, the authors mention, in general, the length of occlusion of the voiceless phones is higher than the same measure of the voiced phones [9].

Looking for information about the acquisition and stabilization of the contrast of voicing of stops in Brazilian Portuguese (BP), this research aims to analyze the contrast of voicing from the description of the phonological system considered typical. For this, it was formulated the hypothesis that children with typical phonological development (TPD) have acoustic characteristics responsible for the voicing contrast close to the same approximate characteristics of adult subjects, marking so the contrast of voicing not only at the level of perceptual hearing analysis, but also by means of acoustic analysis.

It is believed that the acoustic description of the parameters responsible for the distinction between voiced and voiceless stops based on the speech of subjects with no speech disorders, besides providing knowledge of linguistic, articulatory and acoustic patterns of the language in case, still provides the support for the interpretation of phonological errors on the feature [voice], present in the speech clinic.

Thus, the aim of this study is to investigate and compare the acoustic characteristics of voiced and voiceless stops in the speech of children with TPD and also of adults with speech typical patterns of the language.

METHOD

This is an experimental, quantitative and cross-sectional study. Two groups were part of it, one group of adults (GA) and another group of children with TPD (GTPD). To make part of the GA, some undergraduate students of the first year of the Speech, Hearing and Languages major and other majors of the institution where the research was developed were invited to participate. On the other hand, the subjects of the GTPD were selected from two schools of the public system located in the same city the institution of higher education.

In order that the subjects would make part of the GA, the following criteria were considered: consenting to participate in the study by signing the informed consent; having full phonetic and phonological inventories, with all the PB phonemes acquired and stabilized in spontaneous speech; being aged between 19 and 44 years old, have not received any anterior speech therapy; being a native speaker of PB - *gaucho* dialect, and no history of bilingualism.

The exclusion criteria were: the presence of vocal, auditory and language alterations, apparent losses in neurological, cognitive, psychological and/or emotional aspects and alterations in the phono-articulatory organs that were related to the phonological system.

For GTPD, the same inclusion and exclusion criteria were adopted, however, this group should present be aged from four to eight years and 11 months.

For the sample selection, an initial interview and a speech and hearing screening were performed, which were carried out with the use of:

- Initial interview: it was carried out with the subjects of the research, or guardians, in the case of children. It consisted of a few questions, such as: date and place of birth; if he/she had already lived in another city/state; if he/she spoke another language (bilingual?); If he/she had done speech therapy or had any pathophysiological background;

- Assessment of stomatognathic system: with emphasis on observation of the aspect, posture, muscle tension and mobility of the phonoarticulatory organs (tongue, lips, cheeks, soft palate, hard palate and teeth) and their functions (breathing, sucking, chewing and swallowing);
- Assessments of language, speech and voice: for adults, such aspects were observed through speech and spontaneous naming while conducting an interview and naming the figures. For children, these assessments were performed through a logical sequence of four facts. Then, it was asked to the child to organize the sequence of figures and tell a story. Thus, by means of the speech and spontaneous naming some aspects of receptive and expressive, possible phonetic, phonological and oral language, besides vocal quality disorders were observed.
- Hearing screening: from the testing of hearing thresholds by air from 500 to 4000 Hz at 20 dB HL tested (scan mode). It was used the *Interacoustics Screening Audiometer* AS208, properly calibrated.

During the progression of the assessments, some suggestive aspects of neurological, cognitive, psychological and/or emotional were observed, such as the presence of inconsistency, inadequacy or difficulties in responding, difficulty in articulation of neurological origin (dysarthria or dyspraxia), motor impairment, excessive lack of concentration, attention, or lack of cooperation from the child.

In the presence of alterations, the parents and/or guardians, as well the school, were informed about the need for further assessments and referrals to other professionals necessary for each case.

Based on the assessments and on the criteria for inclusion and exclusion considered, this research consists of speech data of 17 adults, aged between 19 and 29 years (mean age = 23 years and six months, SD = 39.1 months), five males and 12 females, and 11 children with TPD, aged between five and eight years (mean age = seven years and five months, SD = 9.9 months). From these ones, six were male and five were female.

To obtain the speech sample that was subjected to acoustic analysis, it was created a list of words/pseudowords of the same linguistic context, with all two-syllable words with penultimate stress, in which all were contrasted stop phonemes (*[‘papa], [‘baba], [‘tata], [‘dada], [‘kaka] e [‘gaga]*). These words/pseudowords were inserted in a vehicle sentence (*“Fala _____ de novo”* – *“Say _____ again”*). Each stop had two series of three replications arranged in a random sequence, a total of 36 sentences for each subject.

The vehicle sentence and its repetitions were presented by using headphones, Sennheiser brand HD280 PRO. There was a silence interval between the presentation of a sentence and the other, in this meantime, the subjects were asked to repeat in normal vocal intensity the all heard phrase, not being controlled the speech rate.

For the procedure of sample recording, it was used an acoustically isolated booth, an omnidirectional microphone (Behringer EMC8000), placed on a pedestal, approximately 4 cm from the mouth of the subject and an external sound card (brand M-AUDIO, model FW 410) connected to a laptop computer (Windows XP SP3). The speech registers were written directly in MATLAB V7.1 SP3 (Simulink Signal Processing Toolbox V6.4) software in Wave file and high resolution (24 bits and 96 KHz).

The data were subsequently analyzed in audio processing software Praat - version 5.1.29 (available at www.praat.org), by observing the waveform and spectrogram broadband. The sampling rate used in the program was 96 KHz and 16 bits.

With the spectrograph, in initial and medial onset, the values of VOT, the length of the vowel after the stop, the amplitude of the burst and the length of occlusion were analyzed, being the length of occlusion only extracted in medial onset.

For extraction of VOT it was considered the burst as the reference point, then, it was researched the prevoicing. The VOT values (in milliseconds - ms) were obtained from spectrogram as follows:

- For the voiceless stops, it was collected the measurement of the length of the segment between the register of burst of the stop to the first pulse of the vowel [a] of the same syllable;
- For voiced stops it was collected the measurement of the segment between the beginning of pre-voicing to the registration of the burst. However, it is noted that the VOT values of voiced segments in what pre-voicing bar anterior to burst was absent were extracted from the spectrogram as in the voiceless stops.

To measure the length (in millisecond - ms) of the vowel present in the target word, it was adopted the criterion of first and last regular adjacent cycle to stop for the determination of the limits of the vowels.

The amplitude (in decibel - dB) of the burst was extracted from the central measurement of the total length of burst. In the presence of multiple bursts, the same procedure was performed for each burst, and after it was carried out an arithmetic mean of the values which were found.

The length (in millisecond - ms) of the occlusion of the target word was measured from the end of the vowel of the stressed syllable (last regular cycle of the vowel) until the beginning of the burst of the next stop, in medial onset. In cases which the stressed vowel was followed by a portion with spectral characteristics of noise (breathy vowel), this one was also considered within the interval of occlusion.

It was verified that before the data were subjected to statistical analysis, the words/pseudowords that presented omission of segments or inaccurate production of any of the analyzed parameters were excluded from the sample. And also, anterior to the application of statistical tests, it was performed for each subject the mean values of each acoustic parameter which was considered in all repetitions of each target word.

This study was approved by the Ethics and Research Committee of the institution in which was carried out, under the number 23081.008886/2009-29. All subjects were invited to participate and informed about it. The authorization of participation in the study was obtained by signing the Consent Form by the research subjects, or parents/guardians, in case of children.

First of all, every single acoustic register of voiced and voiceless stops were registered and tabulated individually, by subject and in each separately group (GA and GTPD). After, the voiced and voiceless acoustic registers of the stops of each group were statistically faced by using the Wilcoxon test. Then, the acoustic registers were statistically compared between the GA and the GTPD, through the Mann-Whitney test.

The first selected test is used for analysis of related samples and the second one to test two independent groups, being one of the most powerful non-parametric tests. These tests were chosen because of non-normal distribution and the sample size[10]. Nonparametric tests assign ranks to the measures of the variables, so that the median, mean, standard deviation, variance and coefficient of variation values were selected to synthesize the information from the sample.

The computer program used for the analysis was the SAS System for Windows (Statistical Analysis System), version 8.02, and the significance level was 5% ($p < 0.05$).

RESULTS

In Table 1, the comparisons between the voiced and voiceless acoustic registers of stops are present, in initial and medial onset, in GA.

For this group, it was found that the length of VOT values were higher for the voiced stops and, most of them had a previous voicing anterior to the release of occlusion when compared to the same VOT values of voiceless stops, with statistically significant results.

Longer lengths of the vowel were found [a], they were present in the target word, when preceded or followed by a stop sound, than when front to a voiceless stop, with statistically significant differences

In relation to the amplitude of burst, it was observed that this is slightly higher during the production of the voiced phones in comparison to voiceless phones. Only the comparison, of the amplitude of burst between [p] and [b] in medial onset, was not statistically significant.

The length of occlusion, acoustic parameter investigated in medial onset, was superior in the context of voiceless stops when compared to the context of voiced stops, also with statistically significant results.

Table 2 shows the comparisons between acoustic registers of voiced and voiceless stops in initial and medial onset in GTPD.

In this group, it was noticed the distribution of VOT between stops [+ voice] similar to GA, with statistical significance.

On the other hand, in relation to the length of the vowel [a], it was also observed for this group, that it was superior in the context of voiced stop, with statistically significant results.

It was also noted a minor increase in the amplitude of burst during the production of the voiced phones. However, only a significant relationship was established.

Table 1 - Comparison between the acoustic parameters of voiced and voiceless stops in initial and medial onset, in the group of adults (GA)

Parameter	Position in the word	Stop / Context	Median	Mean (dp)	Variance	C.V. (%)	Value of p
VOT (ms)	IO	[p]	14.50	15.7 (3.6)	12.9	22.9	p<0,001*
		[b]	-96.86	-101.9 (29.6)	876.2	-29.0	
		[t]	18.85	19.8 (4.1)	16.8	20.7	p<0,001*
		[d]	-102.50	-95.6 (24.2)	585.6	-25.3	
		[k]	44.67	45.4 (9.4)	88.4	20.7	p<0,001*
		[g]	-81.84	-80.4 (28.3)	800.9	-35.2	
	MO	[p]	19.95	19.0 (4.1)	16.8	21.6	p<0,001*
		[b]	-91.64	-86.3 (15.3)	234.1	-17.7	
		[t]	25.15	26.3 (6.7)	44.9	25.5	p<0,001*
		[d]	-82.65	-78.3 (15.0)	225.0	-19.2	
		[k]	48.20	49.4 (7.8)	60.8	15.8	p<0,001*
		[g]	-62.35	-64.0 (16.2)	262.4	-25.3	
LENGTH OF VOWEL (ms)	IO	[p]	152.66	154.5 (18.5)	342.2	11.9	p<0,001*
		[b]	196.10	190.9 (19.7)	388.1	10.3	
		[t]	166.29	164.0 (14.8)	219.0	9.0	p<0,001*
		[d]	210.12	208.5 (24.0)	576.0	11.5	
		[k]	162.68	159.0 (17.9)	320.4	11.2	p<0,001*
		[g]	217.13	218.8 (23.8)	566.4	10.9	
	MO	[p]	113.97	114.7 (27.7)	767.3	24.2	p<0,001*
		[b]	131.11	128.2 (21.1)	445.2	16.5	
		[t]	111.62	109.9 (25.4)	645.2	23.1	p<0,001*
		[d]	130.35	126.6 (24.9)	620.0	19.7	
		[k]	108.21	106.6 (25.2)	635.0	23.6	p<0,001*
		[g]	131.76	129.8 (26.6)	707.6	20.5	
AMPLITUDE OF *BURST* (dB)	IO	[p]	66.53	64.4 (8.4)	70.6	13.0	p<0,001*
		[b]	67.13	65.9 (7.1)	50.4	10.8	
		[t]	62.04	60.6 (6.9)	47.6	11.4	p<0,001*
		[d]	62.52	62.5 (6.8)	46.2	10.8	
		[k]	58.43	56.8 (5.8)	33.6	10.2	p<0,001*
		[g]	59.30	58.4 (5.7)	32.5	9.8	
	MO	[p]	65.96	64.3 (9.2)	84.6	14.3	p=0.404
		[b]	65.97	65.2 (6.7)	44.9	10.3	
		[t]	56.96	57.5 (6.4)	40.9	11.1	p<0,001*
		[d]	61.06	60.7 (6.1)	37.2	10.0	
		[k]	57.46	55.7 (5.7)	32.5	10.2	p<0,001*
		[g]	58.17	57.9 (5.7)	32.5	9.8	
LENGTH OF OCCLUSION (ms)	MO	[p]	150.99	141.4 (25.5)	650.2	18.0	p<0,001*
		[b]	97.90	96.1 (14.4)	207.4	14.9	
		[t]	130.11	132.9 (23.9)	571.2	17.9	p<0,001*
		[d]	90.74	87.6 (13.6)	184.9	15.5	
		[k]	119.03	118.5 (21.5)	462.2	18.1	p<0,001*
		[g]	73.98	73.5 (14.0)	196.0	19.0	

Caption 1: sd – standard deviation; C.V. – coeficiente of variation; VOT – *voice onset time*; IO – initial *onset*; MO – medial *onset*; ms – milliseconds; dB – decibels; * - statistically significant results. Statistical test used = *Wilcoxon*, with p<0,05.

Table 2 - Comparison between the acoustic parameters of voiced and voiceless stops in initial and medial onset in the group of children with typical phonological development (GTPD)

Parameter	Position in the word	Stop / Context	Median	Mean (dp)	Variance	C.V. (%)	Value of p
VOT (ms)	**IO**	[p]	18.89	18.9 (5.0)	25.0	26.5	**p=0.001***
		[b]	-96.16	-95.9 (26.5)	702.2	-27.6	
		[t]	22.18	22.0 (4.9)	24.0	22.2	**p=0.001***
		[d]	-105.90	-108.3 (35.8)	1281.6	-33.1	
		[k]	43.02	46.5 (13.5)	182.2	29.0	**p=0.001***
		[g]	-70.15	-76.5 (52.7)	2777.3	-68.9	
	MO	[p]	21.06	20.9 (4.9)	24.1	23.4	**p=0.001***
		[b]	-73.50	-70.2 (18.2)	331.2	-25.9	
		[t]	28.54	26.4 (5.1)	26.0	19.3	**p=0.001***
		[d]	-72.37	-63.8 (26.8)	718.2	-42.0	
		[k]	43.34	44.1 (9.1)	82.8	20.6	**p=0.001***
		[g]	-53.69	-49.4 (24.2)	585.6	-48.9	
LENGTH OF VOWEL (ms)	**IO**	[p]	141.07	141.9 (19.6)	384.16	13.8	**p=0.001***
		[b]	173.54	174.6 (21.7)	470.9	12.4	
		[t]	130.54	148.7 (38.3)	1466.9	25.8	**p=0.001***
		[d]	188.81	190.4 (31.8)	1011.2	21.4	
		[k]	158.20	148.4 (25.8)	665.6	17.4	**p=0.001***
		[g]	204.93	200.2 (33.8)	1142.4	16.9	
	MO	[p]	93.39	97.2 (22.3)	497.3	22.9	p=0.320
		[b]	106.63	101.5 (18.6)	345.9	18.3	
		[t]	90.81	90.6 (19.8)	392.0	21.8	**p=0.019***
		[d]	105.23	103.6 (18.6)	345.9	17.9	
		[k]	85.93	83.2 (16.1)	259.2	19.4	**p=0.032***
		[g]	99.72	98.2 (26.1)	681.2	26.6	
AMPLITUDE OF *BURST* (dB)	**IO**	[p]	63.37	62.9 (10.1)	102.1	16.1	p=0.123
		[b]	65.49	64.3 (10.1)	102.1	15.7	
		[t]	61.47	59.7 (10.6)	112.4	17.8	**p=0.005***
		[d]	63.60	62.0 (9.4)	88.4	15.2	
		[k]	57.40	57.6 (8.5)	72.2	14.8	p=0.520
		[g]	59.41	58.0 (9.2)	84.6	15.9	
	MO	[p]	61.69	62.2 (9.3)	86.5	14.9	p=0.175
		[b]	63.69	63.8 (9.9)	98.0	15.5	
		[t]	57.36	58.1 (9.7)	94.1	16.7	p=0.175
		[d]	62.08	59.5 (9.2)	84.6	15.5	
		[k]	55.23	56.3 (8.9)	79.2	15.8	p=0.206
		[g]	58.35	57.2 (9.3)	86.5	16.3	
LENGTH OF OCCLUSION (ms)	**MO**	[p]	127.54	128.9 (15.4)	237.2	11.9	**p=0.001***
		[b]	85.37	85.0 (8.0)	64.0	9.4	
		[t]	125.84	125.1 (25.6)	655.4	20.5	**p=0.001***
		[d]	89.86	86.3 (15.8)	249.6	18.3	
		[k]	117.10	115.4 (21.4)	457.9	18.5	**p=0.001***
		[g]	69.68	71.4 (11.4)	129.9	15.9	

Caption 2: sd – standard deviation; C.V. – coeficiente of variation; VOT – *voice onset time*; IO – initial *onset*; MO – medial *onset*; ms – milliseconds; dB – decibels; * - statistically significant results. Statistical test used = *Wilcoxon*, with p<0,05.

The results also showed longer length of occlusion of the phonoarticulatory organs during the production of voiceless stops, with statistically significant results.

Tables 3 and 4 present comparisons of acoustic parameters between the GA and GTPD groups, for each phoneme and in initial and medial onset. Statistically significant differences between groups were observed for the parameters of vowel length in the context of the stop [b], in initial onset and, medial onset, for the parameters of VOT of [b], vowel length in the context of the stops [b], [e], [d], [k] and [g] and length of occlusion [b]. Analyzing the results, there were few significant differences between the groups. However, when considered present, they were mostly in medial onset and unstressed syllable.

Table 3 - Comparison of acoustic parameters in initial onset between the two groups - adults (GA) and children with typical phonological development (GTPD)

Parameters	Stops/Context	Median GA	Median GTPD	Value of p
VOT (ms)	[p]	14.50	18.89	p=0.086
	[b]	-96.86	-96.16	p=0.466
	[t]	18.85	22.18	p=0.290
	[d]	-102.50	-105.90	p=0.410
	[k]	44.67	43.02	p=0.944
	[g]	-81.84	-70.15	p=0.495
Length of Vowel (ms)	[p]	152.66	141.07	p=0.138
	[b]	196.10	173.54	**p=0.041***
	[t]	166.29	130.54	p=0.359
	[d]	210.12	188.81	p=0.213
	[k]	162.68	158.20	p=0.359
	[g]	217.13	204.93	p=0.165
Amplitude of *burst* (dB)	[p]	66.53	63.37	p=0.589
	[b]	67.13	65.49	p=0.410
	[t]	62.04	61.47	p=0.724
	[d]	62.52	63.60	p=0.760
	[k]	58.43	57.40	p=0.906
	[g]	59.30	59.41	p=0.724

Caption 3: GA – group of adults; GTPD – group of children with typical phonological development; VOT – *voice onset time*; ms – milliseconds; dB – decibels; * - statistically significant results.
Statistical test used = *Mann-Whitney*, with level of significance of 5%.

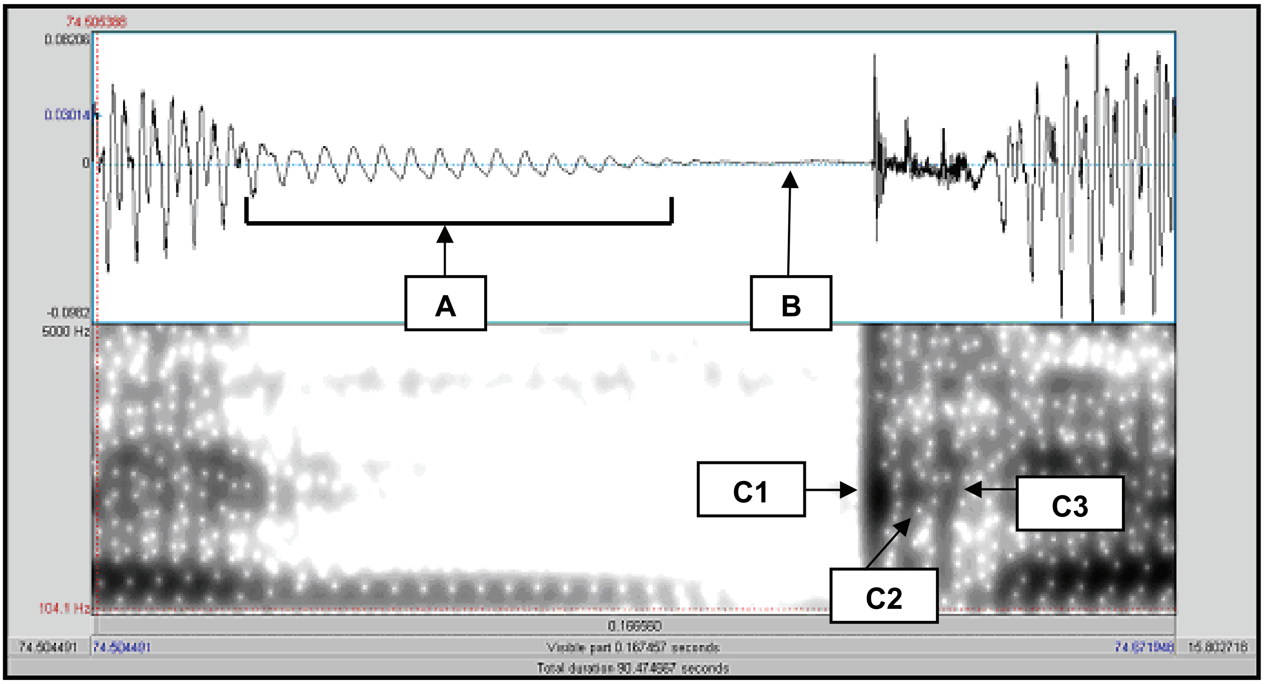
Table 4 - Comparison of acoustic parameters in medial onset between groups - adults (GA) and children with typical phonological development (GTPD)

Parameters	Stops/Context	Median GA	Median GTPD	Value of p
VOT (ms)	[p]	19.95	21.06	p=0.196
	[b]	-91.64	-73.50	**p=0.023***
	[t]	25.15	28.54	p=0.724
	[d]	-82.65	-72.37	p=0.126
	[k]	48.20	43.34	p=0.051
	[g]	-62.35	-53.69	p=0.063
Length of Vowel (ms)	[p]	113.97	93.39	p=0.126
	[b]	131.11	106.63	**p=0.002***
	[t]	111.62	90.81	**p=0.041***
	[d]	130.35	105.23	**p=0.023***
	[k]	108.21	85.93	**p=0.006***
	[g]	131.76	99.72	**p=0.006***
Amplitude of *burst* (dB)	[p]	65.96	61.69	p=0.495
	[b]	65.97	63.69	p=0.410
	[t]	56.96	57.36	p=0.869
	[d]	61.06	62.08	p=0.724
	[k]	57.46	55.23	p=0.906
	[g]	58.17	58.35	p=0.589
Length da Occlusion (ms)	[p]	150.99	127.54	p=0.078
	[b]	97.90	85.37	**p=0.041***
	[t]	130.11	125.84	p=0.557
	[d]	90.74	89.86	p=0.906
	[k]	119.03	117.10	p=0.724
	[g]	73.98	69.69	p=0.760

Caption 4: GA - group of adults; GTPD - group of children with typical phonological development; VOT - Voice Onset Time, ms - milliseconds; dB - decibels; * - statistically significant results.
Statistical test used = Mann-Whitney, with a significance level of 5%.

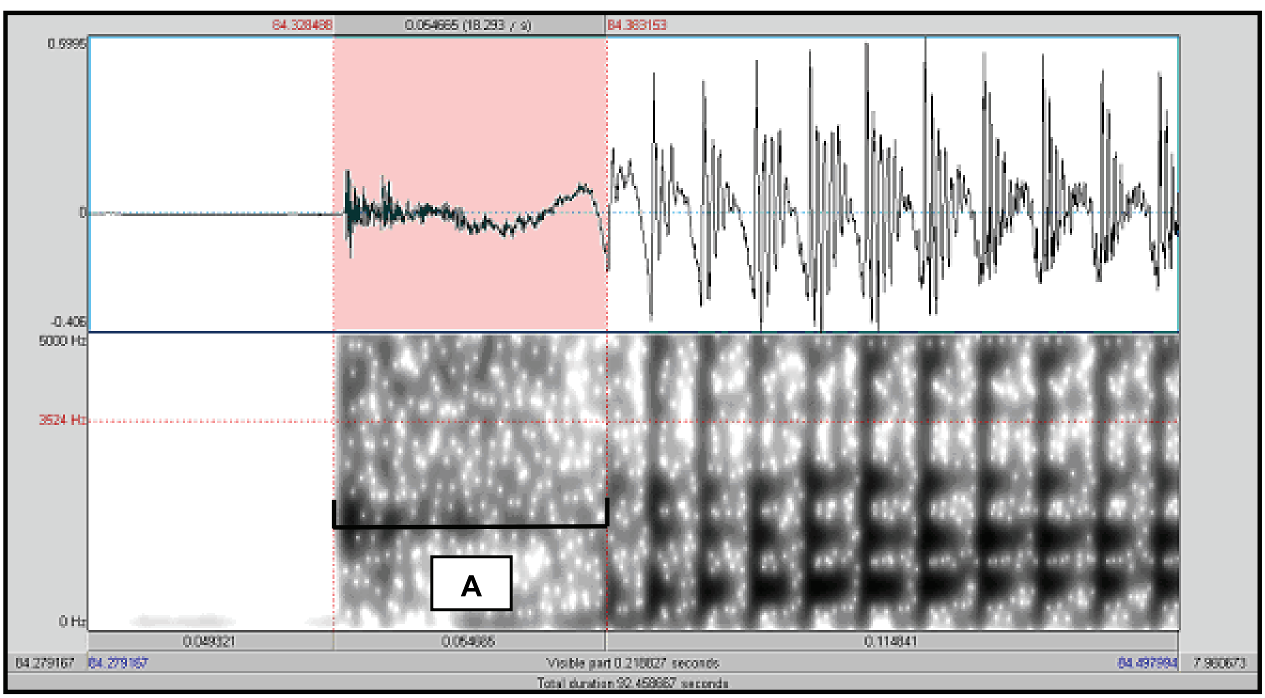
Furthermore, when analyzing the spectrogram trace of stops produced by the subjects of the two groups, some not common characteristics to all emissions were observed, such as:

- Absence of voicing during some productions of voiced stops (Figure 1);
- Presence of multiple bursts during the production of voiced and voiceless stops (Figure 1);
- Production of a portion with spectral characteristics of noise (breathy vowel) post to the stressed vowel (Figure 1);
- Presence of aspiration during the production of voiceless stops, especially in relation to the dorsal [k] (Figure 2).



Caption: A = *breathy vowel*; B = absence of pre-voicing bar; C1, C2 e C3 = multiple *bursts*

Figure 1 –Production of stop [g] in initial onset and visualization of breathy vowel, the absence of pre-voicing bar and multiple bursts - the production of a subject from the GA



Caption: A = aspirated stop VOT = 54.66 ms.

Figure 2 - Production of stop [k], initial onset, with aspiration - production of a subject from the GA

DISCUSSION

The results of this study indicate the VOT as a robust and highly reliable cue to mark the voicing contrast of stop segments, which corroborates many researches in the literature, which also mention the influence of this temporal parameter in the identification of a coordination between glottic and supraglottic settings that are responsible for the production of these consonants [7,9,11,12].

Statistically significant differences were observed between the VOT of voiced and voiceless stops, so the VOT of voiced phones was longer than the VOT of voiceless ones, in agreement with other authors who investigated this acoustic parameter in speakers of BP [4,7].

Not only the length of VOT values, but also the presence of anterior glottic activity to burst, observed during the production of voiced segments, and absent in voiceless segments, marks the contrast feature [voice] at this sound class [4,7,11], as confirmed by this study.

The length of the vowel also proved to be a decisive acoustic parameter for the differentiation of the production of voiced and voiceless consonants. From the observations in this study, the length of the vowel when in the context of voiced stop, presents longer when front to a voiceless stop, agreeing with other studies [4,6,7,9].

In relation to the amplitude of burst, it was found that it is slightly more intense during the production of the voiced phones, with a greater number of statistically significant results in GA. This result is different from some studies [4,5], which mention that the amplitude of release of the occlusion is higher in voiceless consonants.

A study [5] that investigated the speech of children who had a difficulty in stabilizing the feature [+ voice] of stops, showed that the increase in amplitude generated during the production of voiceless phones may be related to the increase of the intraoral pressure. However, the authors also claim that this acoustic correlate does not always prove as a strongly intervening factor in stop contrasting voicing. This situation was also observed in this study, once children with TPD presented only a statistically significant difference when comparing the amplitude of burst between the stops [+ voice].

Thus, the findings in this study, related to the amplitude of burst, suggest that this acoustic cue can be very robust, i.e., secondary to the contrast [+ voice] of stops. Once this was the acoustic parameter that showed lower statistical significance from the tests. What leads to the assertion that stop phonemes have redundant cues in identifying the contrast of voicing [4]. Thus, before a wide variety of acoustic properties, it seems that not all this information is essential to the speaker during encoding process of linguistic segments [11].

In addition to this interpretation, this result also refers to the fact that children with TPD are anchored, initially, in primary cues during the development of a particular contrast. From these more robust cues, according to their neuromotor development, they stabilize the contrast, also with the stabilization of less robust cues.

With regard to the length of occlusion of the phonoarticulatory organs with was carried out during the production of stop phonemes, statistically significant results were also found, in the sense that this acoustic register is greater in voiceless stops, in agreement with other authors [8].

The vast majority of the results showed that the investigated acoustic cues are responsible for the contrast in voicing of stops in both groups.

In the case of the comparison between the acoustic parameters between the GA and GTPD, as shown in Tables 3 and 4, it was found that the studied groups had many similarities in relation to the implementation of the acoustic cues that are responsible for the contrast of voicing in stop consonants of BP. Thus, it was found that children with TPD, in the investigated age group of this study, have already demonstrated domain of the feature [voice]. This finding was reported by studies on phonological acquisition[1-3], and also enhanced by the use of acoustic analysis [7], instrument capable of showing with clarity and precision the articulatory and acoustic manipulations performed during speech [4,7,13-15].

However, it is noteworthy that even in smaller numbers, some differences were also found between the groups, and these mostly in the unstressed syllable in medial onset. So, it is assumed that the interaction of these linguistic variables (medial onset more unstressed syllable) seems to provide an unstable or unfavorable context for the production of stop consonants [16], even though it is due to effects of co-articulation or also due to a lower perceptual salience of this syllabic position and tonicity. What is also reinforced by other authors, who state that stops are generally more strongly articulated in prosodically stronger locations (in the beginning of the word and at the stressed syllable) [17]. However, this finding differs from another study that aimed to describe the acquisition of the feature [voice] in subjects with phonological disorders submitted to phonological therapy. In that work, the position of medial onset proved to be the most favorable to the voicing of stops [18].

Other studies have also investigated the determinant acoustic parameters in differentiating voiced and voiceless stops from the comparison of the productions of adult speakers, with typical established patterns of the target language, and children in the process of development of these patterns [7,19-22].

In a study which involved 19 children and adult speakers of English, the author observed that both children, with an mean age of five years, as adults, presented differences in VOT between the pairs - [p] versus [b] and [t] versus [d], as in the present study. When comparing both groups, no significant difference was also found for the mean and median of VOT, as well as for the length of vowels and aerodynamic measures. However, in general, it was observed a greater variability in terms of production in the group of children, which can be also confirmed by some measurements of dispersion in Tables 1 and 2.

The occurrence of a greater variability in relation to the production of VOT in the speech of children was also quoted by another researcher [21]. The decrease in variability of VOT suggests an increased coordination between oral and glottal gestures through time, showing thus a relationship between gestural reorganization and language development in children [23].

Similarities in the VOT values between adults and children were not observed in another study [20]. However, it should not be reliably compared and generalized to the findings of this study, once it refers only to the voiceless labial stop of VOT and also because they are the speech data of younger children, with a mean age of 19 months, who have not had totally established the contrast of voicing

In the case of stop phonemes of BP themselves, a survey [7] while analyzing the speech of children from three to 12 years, found that the VOT and vowel length were adequate registers to identify the contrast of voicing of stop phonemes and also in the speech of children. These results are consistent with the results that are presented here.

Other acoustic features, not commonly described in the literature, were also found in the present study. One would be the lack of pre-voicing in some voiced stops. Even though not so frequent, this fact can be explained by the presence of multiple bursts and/or breathy vowel, which may have been used in order to “mask” the absence of pre-voicing bar, and thus maintain the perception of these sounds still appropriately.

The presence of alterations in pre-voicing bar, multiple bursts and breathy vowel bar are mentioned in the literature as not common features found in the speech of an adult, native speaker of BP, being probably present due to the lack of maturation of the phonoarticulatory organs, once they were found only in children aged three years [13]. However, this proposition differs from that one found in this study, being both the GA as the GTPD, subjects with typical phonological patterns, such records were evidenced.

Through some high values of VOT for voiceless stops, it was also evidenced the presence of aspiration, in its majority corresponding to the dorsal consonant [k]. According to a found research [24], one slightly voiceless aspirated stop is identified when the VOT values are close to 50 ms. It is noteworthy that in BP, as opposed to other languages, the presence or absence of aspiration does not present distinctive value [7].

The comparison of acoustic parameters in children with TPD and in adults, should also be emphasized in other studies. Investigations enhance the understanding of the implementation of contrast of voicing during the neuromuscular phonological development and maturation. Undoubtedly the understanding of the contrast of stop sound segments and its variation in the normal population, provide a sustainable basis for understanding the distinction of voicing also in the various speech disorders found in clinical practice.

In order to obtain a standardization and a more extensive description of these acoustic registers for BP, it is suggested to carry out further research that include a greater number of subjects, and that these registers relate to some linguistic and extralinguistic variables, as gender, age, speech rate, aerodynamic measures, different modes of enunciation (repetition, reading, spontaneous speech, etc..), different vowel contexts, among others.

CONCLUSION

From these results, it was possible to conclude that the investigated acoustic cues - VOT, vowel length, amplitude of burst and length of occlusion - are parameters that are involved in characterizing the contrast of voicing of stop phones of BP.

Moreover, the results also indicate many similarities in relation to the use of these acoustic parameters between the GA and children with typical phonological patterns, agreeing with the hypothesis which was initially formulated for this study. However, some differences are evident, these ones occur, mostly, in the medial and unstressed syllable.

RESUMO

Objetivo: investigar e comparar as características acústicas das plosivas surdas e sonoras na fala de crianças com desenvolvimento fonológico típico e, de adultos com padrões de fala típicos da língua. **Método:** a amostra do estudo é composta por dois grupos - 17 adultos e 11 crianças com desenvolvimento fonológico típico. Por meio de palavras/pseudopalavras *(['papa], ['baba], ['tata], ['dada], ['kaka] e ['gaga])* inseridas em frases-veículo ("*Fala ___ papa de novo*"), mediu-se o *voice onset time*, a duração da vogal, a amplitude do *burst* e a duração da oclusão. Foram comparados os registros acústicos de plosivas surdas e sonoras intra e intergrupo por meio de testes estatísticos (p<0,05). **Resultados:** em geral, observou-se que: (1) o *voice onset time* foi maior para as plosivas sonoras em comparação às surdas; (2) a duração da vogal quando seguida ou precedida por uma plosiva sonora foi mais longa do que diante de uma plosiva surda; (3) a amplitude do *burst* foi levemente superior durante a produção dos segmentos sonoros e; (4) a duração da oclusão se mostrou superior no contexto de plosivas surdas. Também se observou que adultos e crianças apresentam muitas similaridades em relação à produção desses parâmetros. **Conclusão:** pode-se concluir que as pistas acústicas investigadas apresentam-se como fortes parâmetros envolvidos na caracterização do contraste de sonoridade das plosivas. Além disso, os resultados também indicam muitas semelhanças entre adultos e crianças com padrões fonológicos típicos. No entanto, quando algumas diferenças são evidentes, essas ocorrem na posição de sílaba átona e medial.

DESCRITORES: Acústica da Fala; Adulto; Criança; Espectrografia do Som/análise; Fala

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