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The impact of a dysfluency environment on the temporal organization of consonants in stuttering

O impacto do contexto da disfluência na organização temporal de consoantes na gagueira

Leticia Correa Celeste[1], *Vanessa de Oliveira Martins-Reis*[2]

ABSTRACT

Purpose: To analyze and compare the voice onset time (VOT) in Brazilian Portuguese speakers who stutter and those who do not, focusing on three different moments of speech: fluent, pre-dysfluent and post-dysfluent environments. **Methods:** Twenty participants (n=10 with stuttering and n=10 without stuttering) were recorded. The data were transcribed and segmented for acoustic analysis, and it was extracted tokens of Brazilian Portuguese voiceless stops /p/, /t/ and /k/. Tokens were classified according to whether they were produced by people who stutter (PWS) or by people who do not stutter (PWnS), and according to their environment in speech (i.e., in fluent speech, pre-dysfluency, and post-dysfluency). For comparisons within groups it were used the Friedman and Wilcoxon tests, and the Mann-Whitney test was used in intergroup comparisons. Statistical analyses were executed using SPSS 14.0 with the significance level set at α=0.05. **Results:** VOT in stuttering and non-stuttering speakers differed most in the environment of pre-dysfluencies, during which stuttering speakers show significantly longer VOT than speakers who do not stutter. After passing through a moment of dysfluency, however, stuttering speakers' VOT returns to measures similar to non-stuttering speakers'. **Conclusion:** In pre-dysfluent and post-dysfluent speech, PWS produces longer VOT than PWnS. In the fluent speech of PWS, the stops behave differently. The implications of these results for speech motor control are discussed.

Keywords: Stuttering; Acoustics; Planning; Motor skills; Speech

RESUMO

Objetivo: Analisar e comparar o *voice onset time* (VOT) em falantes do português brasileiro com e sem gagueira, com foco em três momentos diferentes de discurso: fala fluente, pré-disfluência e pós-disfluência. **Métodos:** Foram feitas gravações da fala de 20 participantes (n=10 com gagueira e n=10 sem gagueira). Os dados foram transcritos e segmentados para análise acústica e segmentos de oclusivas não vozeadas do Português Brasileiro, /p/, /t/ e /k/ foram extraídos. Os segmentos foram classificados por grupo - se foram produzidos por pessoas que gaguejam (PG) ou por pessoas que não gaguejam (PnG) - e de acordo com o contexto/ambiente de fala (ou seja, na fala fluente, na pré-disfluência, e na pós-disfluência). Os testes Friedman e Wilcoxon foram utilizados para comparação dentro dos grupos e o teste de Mann-Whitney, em comparações intergrupos. As análises estatísticas foram executadas usando SPSS 14.0, com nível de significância de α=0,05. **Resultados:** O VOT de falantes com e sem gagueira diferiu mais no ambiente de pré-disfluência, durante o qual, falantes com gagueira apresentaram VOT significativamente mais longo do que falantes que não gaguejavam. Depois de passar por um momento de disfluência, no entanto, o VOT dos participantes com gagueira retornou a medidas semelhantes às pessoas que não gaguejavam. **Conclusão:** Nos ambientes de pré-disfluência e pós-disfluência, as PG produzem VOT mais longos do que as PnG. Já no discurso fluente de PG, as oclusivas se comportam de forma diferente. São discutidas as implicações desses resultados para o controle motor da fala.

Descritores: Gagueira; Acústica; Planejamento; Destreza motora; Fala

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Study conducted at the Phonetic Laboratory, Universidade Federal de Minas Gerais – UFMG – Belo Horizonte (MG), Brazil.

(1) Universidade de Brasília – UnB – Brasília (DF), Brazil.
(2) Universidade Federal de Minas Gerais – UFMG – Belo Horizonte (MG), Brazil.

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Correspondence address: Leticia Correa Celeste. Centro Metropolitano, Conjunto A, lote 01, Brasília (DF), Brasil, CEP: 72220-900. E-mail: leticiaceleste@unb.br

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INTRODUCTION

Acoustically, the production of stop consonants involves three stages: (1) the gap, (2) the release burst, and (3) the interval between the burst and the beginning of phonation. The interval between the beginning of the burst and the beginning of phonation is called voice onset time, or VOT(1,2). Fluent speech requires speakers to efficiently coordinate oral-facial muscles and the vibration of vocal folds, and these skills are often lacking in people who stutter (PWS)(3). Such incoordination can result in speech disruptions, compromising articulatory stability. This phenomenon may be observed in acoustic measurements, and through further examination of stops in context, VOT measures may shed further light on articulatory instability in PWS.

Generally, speech production requires three phases: elaboration, preparation, and execution. These phases must be accurately controlled, and their temporal basis coordinated(4). Each articulatory speech gesture can be seen as a 'coordinated structure' of different factors(1), based on either theories which support exclusive central control or theories which support speech as a dynamic task of coordinated articulatory movements(4). Each sound involves the coordination of specific muscular movements, which must be modified over a period.

In order to produce the stop consonants, it is initially necessary for a speaker to decide whether the vocal folds will participate — that is, whether "voicing" will be involved.

Independently of the vocal folds vibration, the palate must be raised so that the nasal tract is blocked and the air is prevented from escaping through the oral cavity(1), generating a build-up of air and increasing pressure in the mouth. Then, the articulators involved release the airstream(5).

The definition of which articulators are involved is important, as there is a relation between the place of articulation and the duration of the intra-oral air pressure release(6). In a study of several languages(7) the authors showed that velar stops present a higher VOT than anterior stops. The complexity of the articulatory movements involved in the production of stop consonants confirms the need for studies of people who have communication disorders.

Because of the articulatory complexity of stops, VOT has been studied in communication disorders such as dyslexia(8), stuttering(3,9), aphasia and dysarthria(10), among others. Recent studies suggest that basal ganglia have an important role in speech timing(4), and when these are affected by disorders, speakers may show great variation in the duration of stops. A study of individuals with Parkinson's disease showed that these patients tend to mix VOT patterns, for example by strengthening the front stops, because the more forward the stops are, the shorter is the VOT(7). On researching the relationship between Huntington's chorea and voiceless stops(1), there was a decrease in the VOT mean over time. Researches also suggest that stuttering may be related to a dysfunction of the basal ganglia(11-13).

Stuttering is considered to be a speech fluency disorder(14) centering on difficulties with motor control in speech(11-12,15-17). PWS present disruption in their speech processing ability with temporal stability(18), and for that reason, there have been more and more researchers studying VOT among PWS(3,9,19,20) , since VOT is a standard methodology for investigating temporal features of speech. A study showed(21) that PWS produce a longer VOT for voiceless stops, while another one(22) observed that stuttering children present a longer VOT for both voiced and voiceless stops when compared to non-stuttering children.

In a study with stuttering and non-stuttering native speakers of German, participants were instructed to produce isolated syllables (/papapas/, /tatatas/, and /kakakas/) with stress on the second syllable. The results showed that even in fluent speech, the stuttering participants presented a higher variation in the duration of the first syllable production(20). On a research of /p/ in sentences, analyzing the difference between the productions of stuttering and non-stuttering participants through eletroglotography and acoustic measurements, the results suggest a difference between the two groups in the duration of intervals of oral-laryngeal subsystem events(9).

A Brazilian study compared how stutterers and non-stutterers produce stops preceded by a vowel (e.g. [ap]). The results indicated that PWS' segments were longer, and the difference increased with the degree of stuttering(23).

In order to verify the use of VOT as a parameter of speech naturalness in comparing the outcomes of two stuttering treatment procedures, authors analyzed the production of /b/ in sentences uttered by stuttering and non-stuttering speakers(3). They found VOT to be a satisfactory parameter: stutterers exhibited longer VOTs, which was interpreted as a dysfunction of the neuromotor process involved in speech(3).

Research on VOT and its role in stuttering offers important resources for understanding articulatory processes. The present study contributes to this trend, providing an acoustic description of VOT among stuttering and non-stuttering speakers of Brazilian Portuguese considering the dysfluency environment as main tool on understanding of planning motor error. The purpose of this study is to verify how voice onset time (VOT) is produce by people who stutter (PWS) focusing on three different moments of speech: fluent, pre-dysfluent and post-dysfluent environments.

METHODS

The study was approved by the Research Ethics Committee of *Universidade Federal de Minas Gerais* (UFMG), resolution number CAAE – 0308.0.203.000-11. All participants signed a term of free and informed consent; according to the demands of the 196/96 act (BRAZIL. Act MS/CNS/CNEP number 196/96 of October 10th 1996).

The 20 participants in this study were divided in two different groups: 10 in the experimental group (PWS) and 10 in the control group (non-stutterers). All were males between the ages of 20 and 45, since sex and age appears to influence on VOT(24). Criteria for participation included an absence of general health deficits and negative screening results for communication disorders (language, hearing, neurologic, cognitive, etc.). All participants were screened by a speech therapist in order to ensure that selection criteria were fulfilled. All members of the experimental group presented developmental stuttering at a moderate to severe level on the scale of Iowa(25), but they had no other sensorial disorders or speech or hearing troubles. None had undergone any kind of treatment to improve their speech. The control group presented normal fluency as measured by the Speech Fluency Assessment Protocol(26).

Two sets of data were collected for the study. To elicit fluent, unrehearsed speech, following the Speech Fluency Assessment Protocol(26), a picture was presented to each participant and the following instructions were given: “Please look at this picture and tell me anything you want about it.” Participants’ responses were audio recorded.

To elicit specific productions of all voiceless stops in Brazilian Portuguese, participants were also asked to read sample sentences aloud. Each participant was given ten sentences to read silently. The sentences featured voiceless stops /p/, /t/, and /k/ in different positions (e.g., word-initial *Eu gosto da **C**arol* ‘I like Carol’; inter-vocalic *eu deixei o re**c**ado* ‘I left the note’). Later, in a soundproof environment, participants were instructed to read the sentences aloud three times into a microphone connected to a Praat-enabled computer (version 5.1.02, 1992-2010, freely available on www.praat.org). The data were stored for later editing and analysis.

All speech samples were transcribed orthographically to identify fluent and dysfluent syllables, and all speech disruptions were classified (hesitation, interjection, revision, unfinished word, word repetition, segment repetition, phrase repetition, syllable repetition, sound repetition, prolongation, blocks, pauses and intrusion of sounds or segments). Syllables were also counted, excluding non-word interjections, revisions, non-finished words, word repetitions, segment repetitions, phrase repetitions, and syllable repetitions; and these totals were used to calculate speech rates and frequencies of speech disruptions.

Speech rate variation has been shown to be an important factor in VOT analysis(21); however, participants’ speech dysfluencies do not necessarily represent a difference in the articulation time of each syllable. For these reasons, measures of speech rate were calculated for each recorded utterance. Speech rate was calculated by dividing the number of syllables by the articulation time (duration of pauses and dysfluencies subtracted from the total duration of the utterance), resulting in the articulation rate. The articulation rate mean was 5.5 syllables/seconds. Sentences whose articulation rate had a standard deviation of higher than 1.5 were eliminated.

The transcribed data were then segmented for acoustic analysis, and tokens of the Brazilian Portuguese voiceless stops /p/, /t/ and /k/ were identified and extracted. The consonants included in the analysis occurred in different sentence positions, and were required to appear in the context V**C**V (vowel-consonant-vowel). Further, the analytical focus centered on syllables in unstressed position. Stressed and utterance-final syllables were excluded because they differ in duration from unstressed syllables.

Three parameters of the voiceless stops were analyzed: the silence or occlusion duration, the VOT, and the total duration. Duration of occlusion was marked between the end of the preceding vowel and the beginning of the release burst. VOT boundaries were marked from the beginning of the burst to the beginning of the following vowel (Figure 1). A triangulation of waveform, spectrogram, and F0 curve was used to determine these boundaries.

To determine the effect of dysfluency environments on voiceless stops, each stop parameter was investigated in the following speech environments:

1. Fluency: there was no dysfluency in the word which preceded or followed the token word;
2. Pre-dysfluency: the stop occurs in a syllable just before a dysfluency, and
3. Post-dysfluency: the stop occurs in a syllable immediately following the dysfluency.

The number of analyzed consonants was greater for PWS than for PWnS. Several PWS asked to reread the sentences, and these additional tokens were included in the data.

Interjudge reliability measures were obtained for determining moments of disfluency in the PWS´s speech. In order to identify moments of dysfluency, a perceptive test was administered to three Brazilian native-speakers. None of them presented stuttering or any other speech, language or auditory disorder. The test was administered individually, in a silent place in each auditor’s home. The auditors were given a piece of paper listing the sentences read by PWS. While listening to the recordings, each auditor was asked to underline moments of dysfluency on the list. The volume of the recordings was adjusted individually according to each listener’s comfort level, and the sentences were played several times so that evaluators could be sure about the labeling. Only markings identified by all the three auditors and the research were included in the analysis.

The statistical analysis entailed separating the groups (PWS and PWnS) and the speech environments as follows: (a) the consonants compared to each other; (b) the consonants in PWS’s speech compared to those in PWnS’s speech; and (c) speech environments compared to each other. Descriptive and inferential measures were calculated. The Friedman and Wilcoxon tests were used for comparisons within groups, and the Mann-Whitney test was used in intergroup comparisons. Statistical analyses were executed using SPSS 14.0 with the significance level set at α=.05.

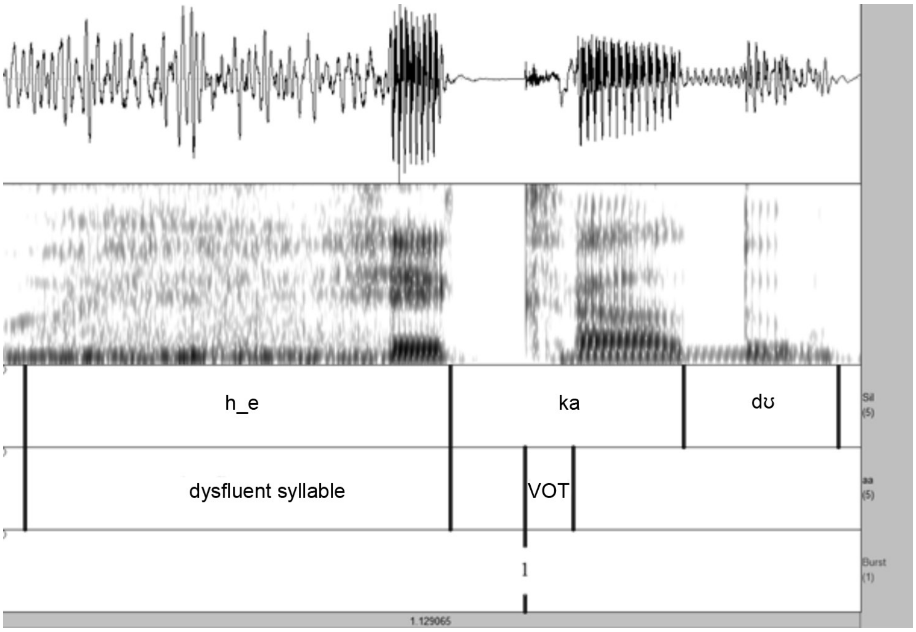

Figure 1. Boundary Identification. First tier (spelling) = transcription of the utterance; second tier (aa) = acoustic analysis of the stop consonant; third tier (B exp) = release burst

RESULTS

The effect of speech environment on consonants and their release bursts was striking. Tables 1 and 2 below show the effects of speech environment on each consonant for both the control and the experimental group. As described above, the analysis of the experimental group comprised three categories: fluency, pre-dysfluency, and post-dysfluency.

For PWS, the acoustic measurements of occlusion time and VOT show differentiated voiceless stops in all speech environments. However, consonants did not differ by total duration measures in post-dysfluent speech. In the control group, voiceless stops differed in occlusion time and VOT measures.

An analysis of the effects of speech environment (PWnS, PWS fluent, PWS pre-dysfluent and PWS post-dysfluent) showed that most *p* values demonstrate a statistically significant difference. In the intergroup analysis (PWnS *versus* PWSs' speech environments), PWS's VOT was longer in five of nine comparisons and was shorter for /t/ in fluent and /p/ in pre--dysfluent environments. The acoustic measures of fluent /p/ showed no difference between PWnS and PWS. The voiceless stop occlusion times were longer for PWS in four of nine comparisons and shorter for /p/ and /k/ in post-dysfluent environments. For consonants, PWS shower higher total duration values in five of nine comparisons; however, durations of /p/ and /k/ were shorter in post-dysfluent environments (Table 3).

Table 3 also shows a comparison of speech environments for PWS. For these speakers, VOT is usually longer in post--dysfluent speech, while occlusion time and total duration are longer in fluent speech. In pre-dysfluent speech, all acoustic measurements for voiceless stops showed higher values than in fluent speech. Tokens in pre-dysfluent environments also generally showed higher values than those in post-dysfluent speech, with the exception of VOT for /p/, which is shorter in pre-dysfluent environments.

DISCUSSION

This study verified the influence of speech environment (fluent, pre-dysfluent and post-dysfluent) on the production of voiceless stops by speakers of Brazilian Portuguese who stutter. For pre-dysfluent speech, PWS measures were higher than those for PWnS in all measurements taken for each consonant. Three possible hypotheses could justify such a difference.

Different theories identify the formulation of language as a primary factor in the production of speech dysfluencies in both fluent speakers as well as the speakers who stutter. One theory argued that dysfluencies are consequences of errors detected during the preparation of the phonetic plan(27). The results found in the pre-dysfluency environment may reflect an adjustment of articulatory gestures to identifying errors in phonetic planning, corroborating all of these ideas.

In neuromotor terms, slower articulation in PWS can be interpreted as a dysfunction in speech processing(3). The hypothesis that stuttering was the result of a dysfunction of the basal ganglia reinforces the idea that the disturbance is directly related to timing in speech production(11,12). This dysfunction of the basal ganglia result of a structural abnormality that affects the flow of information between Broca's area and the motor cortex, ie, between the programming of speech motor planning and execution of movement(15).

A third hypothesis that may account for these results is known as the coarticulatory effect. The phenomenon of

Table 1. Descriptive measures of voiceless stops produced by people people who stutter (PWS) in all three experimental environments and in the control group (PWnS)

Speech environment	Measures	Number	Range	Mean	Median
/p/ Fluent	Occlusion time	31	.06 - .99	.13	.11
	VOT	31	.01 - .03	.02	.02
	Total duration	31	.08 - 1.02	.15	.13
/p/ Pre-dysfluent	Occlusion time	33	.27 - .30	.28	.28
	VOT	33	.01 - .02	.01	.01
	Total duration	33	.28 - .32	.29	.29
/p/ Post-dysfluent	Occlusion time	38	.07 - .08	.07	.07
	VOT	38	.03 - .05	.04	.04
	Total duration	38	.10 - .12	.11	.11
/t/ Fluent	Occlusion time	45	.02 - .13	.08	.08
	VOT	45	.01 - .03	.02	.02
	Total duration	45	.03 - .14	.09	.1
/t/ Pre-dysfluent	Occlusion time	27	.09 - .30	.13	.11
	VOT	27	.01 - .04	.03	.04
	Total duration	27	.12 - .31	.17	.14
/t/ Post-dysfluent	Occlusion time	37	.07 - .09	.08	.08
	VOT	37	.02 - .04	.03	.03
	Total duration	37	.10 - .12	.11	.11
/k/ Fluent	Occlusion time	29	.10 - .99	.12	.1
	VOT	29	.03 - .05	.04	.05
	Total duration	29	.14 - 1.04	.21	.15
/k/ Pre-dysfluent	Occlusion time	28	.09 - .33	.31	.32
	VOT	28	.03 - .08	.08	.08
	Total duration	28	.12 - .40	.38	.39
/k/ Post-dysfluent	Occlusion time	58	.04 - .08	.06	.06
	VOT	58	.01 - .08	.05	.06
	Total duration	58	.07 - .15	.11	.12
/p/ PWnS	Occlusion time	20	.01 - .17	.1	.11
	VOT	20	.01 - .04	.02	.02
	Total duration	20	.02 - .21	.12	.13
/t/ PWnS	Occlusion time	30	.03 - .13	.07	.07
	VOT	30	.02 - .05	.03	.03
	Total duration	30	.05 - .16	.1	.1
/k/ PWnS	Occlusion time	50	.01 - .13	.08	.08
	VOT	50	.03 - .07	.05	.05
	Total duration	50	.05 - .17	.13	.13

Note: VOT = voice onset time; PWnS = speech produced by people who do not stutter

coarticulation has been a central theme in current studies on speech production and can be generally defined as the overlapping of sounds during speech production. This means that the production of sound /b/, for example, is different when produced alone or in syllables /bu/ or /bi/: in the former, /b/ is accompanied by an anticipatory rounding of the lips, while the latter is accompanied by stretched lips. This is just one example of coarticulation in Brazilian Portuguese.

It is to be expected, then, that speech shows wide variability; and speech signal segmentation is difficult given the continuous and reciprocal influence of speech segments, a fact that is virtually universal(28). Some studies have produced the noteworthy finding that coarticulation appears to have similar or identical influences on the speech of those who stutter and those who do not(29), that is, the effect of coarticulation is present in the speech of PWS. Furthermore, coarticulation can be subdivided

Table 2. Comparison of p values: occlusion time, VOT, and consonants' total duration for each speech environment

Environment	Measures	Friedman test	p-values	Wilcoxon test
PWS-Fluent	Occlusion time	18.000	<.001	/t/</p/; /t/</k/
	VOT	43.630	<.001	/t/</p/</k/
	Total duration	40.963	<.001	/t/</p/</k/
PWS-Pre-dysfluent	Occlusion time	44.308	<.001	/t/</p/</k/
	VOT	52.000	<.001	/p/</t/</k/
	Total duration	44.308	<.001	/t/</p/</k/
PWS-Post-dysfluent	Occlusion time	34.108	<.001	/k/</t/</p/
	VOT	48.054	<.001	/t/</p/</k/
	Total duration	1.552	.460	-
PWnS	Occlusion time	9.300	.010	/t/</p/
	VOT	25.848	<.001	/p/</t/</k/
	Total duration	5.200	.074	-

Note: PWS-Fluent = fluent speech produced by people who stutter; PWS-Pre-dysfluent = pre-dysfluent speech produced by people who stutter; PWS-Post-dysfluent = post-dysfluent speech produced by people who stutter; PWnS = speech produced by people who do not stutter; VOT = voice onset time

Table 3. Comparison of p values: groups and speech environments

	Measures	PWnS *vs* PWS fluent	PWnS *vs* PWS pre-dysf	PWnS *vs* PWS post-dysf	PWS fluent *vs* PWS pre-dysf	PWS fluent *vs* PWS post-dysf	PWS pre-dysf *vs* PWS post-dysf
/p/	Occlusion time	.787	<.001	.003	<.001	<.001	<.001
	VOT	.512	<.001	<.001	<.001	<.001	<.001
	Total duration	.689	<.001	.0542	<.001	<.001	<.001
/t/	Occlusion time	.348	.001	.016	<.001	.694	<.001
	VOT	<.001	<.001	.118	<.001	<.001	.002
	Total duration	.299	<.001	.009	<.001	.004	<.001
/k/	Occlusion time	<.001	<.001	<.001	.003	<.001	<.001
	VOT	.046	<.001	.032	<.001	.098	<.001
	Total duration	<.001	<.001	<.001	.003	<.001	<.001

Mann-Whitney Test (p=0.005)

Note: PWS- Fluent = fluent speech produced by people who stutter; PWS- Pre-dysfluent = pre-dysfluent speech produced by people who stutter; PWS- Post-dysfluent = post-dysfluent speech produced by people who stutter; PWnS = speech produced by people who do not stutter; VOT = voice onset time; *vs* = *versus*

into two groups: left-to-right (LR) and right-to-left (RL). The first group, LR, is also called "progressive," because certain properties of one segment are retained and extend into the next segment. The second group, RL, is also called "regressive." Its coarticulation is related to anticipatory effects; that is, one segment influences those that come before it(28). The RL, more common in spontaneous speech, can be explained by cognitive intervention in biological and biomechanical processes(28).

A decrease in articulation speed is expected during dysfluency. In the present study, we evaluated the effect of dysfluency on consonant syllables in pre- and post-dysfluency environments. Findings corroborated that regressive coarticulation is more common than progressive. The effects of dysfluencies were much more striking in pre-dysfluent than in post-dysfluent environments. This fact is apparent in Tables 1, 2 and 3, where the PWS VOT is greater than the PWnS, but the occlusion time tends to be lower in the group with stuttering. Thus, the effects of dysfluencies seem to be bidirectional, predominantly in pre-dysfluent environments.

The variability of phone behavior in fluent PWS speech also supports the findings of a study(20) that demonstrated greater variability in the measures of voiceless occlusive duration among speakers who stutter. However, our study does not corroborate other findings(3,21) because the results on VOT duration for the bilabial phoneme /p/ were virtually the same for speakers who stutter and those who do not, while they were different in the studies cited above. The difference in findings can be explained by differences in the speech environments analyzed. Here, we separate speech dysfluency into three different environmental moments, while those researches(3,21) apparently considered only fluent speech.

It is important to highlight that for the production of fluent /k/, the occlusion time of PWS is much greater than that of fluent speakers (PWnS), offsetting the reduced VOT in determining the duration of the phone. This offers further evidence of the great variability and instability in motor control among individuals who stutter(11,12).

Many studies have shown that changes in the duration of VOT follow a hierarchical order for stops: velar> alveolar> labial(1,2). This study expected that PWS and PWnS would maintain this trend, albeit with higher values for the first group. For PWnS, this relationship remains clear, with statistically significant differences between the consonants. However, our data for PWS did not confirmed this assumption. These results therefore corroborate those reported on a research of temporal organization in speech disorders, in such the duration of the consonants uttered by individuals who stutter do not follow the typical trends determined by location and manner of articulation(30).

CONCLUSION

In pre-dysfluent speech, the stuttering group showed higher durations for all measurements (total duration, VOT, and occlusive duration) taken for each voiceless stop.

Considering that none of the subjects in this study had participated in speech therapy, the results encourage further investigation into whether speech therapy might affect the temporal consonant features described here. We wish to take a conservative approach in interpreting our data, and we acknowledge that the general degree of stuttering among PWS in this study was relatively severe. Future work will need to consider different levels of stuttering severity. In addition, it may be interesting to apply a similar methodology to samples of spontaneous speech.

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