

Article

Interaction of Voice Onset Time with Vocal Hyperfunction and Voice Quality

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Featured Application: This research article investigates whether the acoustic measure Voice Onset Time (VOT) can describe voicing features in patients with vocal hyperfunction.

Abstract: The main aim of the present work was to investigate whether vocal hyperfunction (VH), perceptual voice quality (VQ), gender, and phonetic environment influence Voice Onset Time (VOT). The investigated group consisted of 30 adults, including 19 women ($X = 46.1 \pm 13.7$ years) and 11 men ($X = 47.5 \pm 11.0$ years), who had either phonotraumatic vocal hyperfunction (PVH) and non-phonotraumatic vocal hyperfunction (NPVH). VQ was judged considering the overall severity of dysphonia (OS) and the subcharacteristics of roughness, breathiness, and strain. Phonetic variables such as vowel stress, syllable stress, and mode of speech task were analyzed. Four samples of syllables with [p] plus vowel or diphthong were retrieved from CAPE-V sentences recordings. Acoustic analysis with Praat comprised VOT, mean fundamental frequency (f_0), intensity (SPL dB(A)), and coefficient of variation of fundamental frequency (CV_{f_0} %). VOT was significantly influenced by OS ($p \leq 0.001$) but not by vocal VH condition (PVH versus NPVH) ($p = 0.90$). However, CV_{f_0} was affected by the VH condition ($p = 0.02$). Gender effects were only found for mean f_0 ($p \leq 0.001$) and SPL ($p = 0.01$). All VQ sub characteristics (OS, roughness, breathiness, and strain) correlated with VOT ($p \leq 0.001$) and SPL ($p \leq 0.001$) but not with f_0 . In summary, VOT was affected by voice quality, while it was not affected by vocal hyperfunction conditions. Therefore, VOT has the potential to objectively describe the onset of voicing in voice diagnostics, and may be one underlying objective characteristic of perceptual vocal quality.

Keywords: voice measurement; Voice Onset Time (VOT); vocal hyperfunction; vocal quality**Citation:** Soares, M.F.d.P.; Sampaio, M.; Brockmann-Bauser, M.Interaction of Voice Onset Time with Vocal Hyperfunction and Voice Quality. *Appl. Sci.* **2023**, *13*, 8956. <https://doi.org/10.3390/app13158956>

Academic Editor: Michael Döllinger

Received: 30 May 2023

Revised: 29 July 2023

Accepted: 31 July 2023

Published: 4 August 2023



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1. Introduction

There are many possible applications for acoustic voice analysis techniques, such as measuring specific aspects of vocal quality (VQ), interpreting laryngeal and vocal tract function adjustments related to dysphonia to support voice diagnostics, and guiding voice treatment or training [1]. Acoustic measurement techniques to evaluate VQ include parameters related to the fundamental frequency (f_0), amplitude (SPL), spectrum, or signal waveform, and are applied individually or as combined indices [2].

Vocal hyperfunction (VH) is an etiologic model of voice disorders in which an increased intrinsic and extrinsic laryngeal muscle tension baseline is assumed [3,4]. Hillman et al. 2020 [5] classified VH as either of (i) non-phonotraumatic vocal hyperfunction (NPVH) or (ii) phonotraumatic vocal hyperfunction (PVH). These two conditions vary in phonatory pathophysiology. PVH is associated with structural lesions of the lamina propria, and consequently with prolonged phonotrauma such as vocal nodules, polyps, and further reactive lesions. In contrast, NPVH is related to primary muscle tension dysphonia (pMTD).

Vocal signs and symptoms of VH include dysphonia, increased vocal effort, vocal fatigue, and strain [6,7]. Moreover, elevated activity of the perilaryngeal muscles during phonation related to hyperfunction has been shown to lead to increased pitch and loudness, involuntary voice breaks during phonation, and difficulties in triggering voicing [8].

Despite a quite considerable amount of effort, the literature has not yet indicated a reliable acoustic measure capable of indicating VH [9]. Thus far, a relative increase of fundamental frequency (f_0) has been related to an elevated baseline tension in the laryngeal muscles [10]. While alterations may change vocal fold stiffness, our understanding of the complex adaptation of vocal hyperfunction behavior and its effects on f_0 remains limited. The relative fundamental frequency (RFF) parameter, usually referring to changes in f_0 control at the phonemic level, has been discussed as a promising acoustic measure to describe voicing onset and offset control. RFF has been shown to discriminate between the PVH and NPVH conditions in adults [11–13], to denote treatment effects after voice therapy [12], and to indicate laryngeal tension [14]. However, its implementation as a clinical measure is hindered by its methodological complexity [15], phonetic constraints [16], and dependence on quasi-periodic signals [8].

1.1. Concept of Voice Onset Time

An assessment of voice onset is an integral part of perceptual evaluation in a variety of diagnostic concepts, and is commonly described as vocal attack (rated as soft, breathy, or harsh) [17,18]. The quality of the voicing onset potentially adds information about vocal control and the vibratory behavior of the vocal folds. An objective feasible way to measure vocal onset could improve clinical voice assessment [19].

Voice Onset Time (VOT) is an acoustic measure of the temporal domain. Its calculation relies on the onset of voicing to phonologically distinguish between voiceless [p, t, k] and voiced [b, d, g] stop consonant productions [20,21]. Studies in Brazilian Portuguese (BP) have pointed out that VOT objectively discriminates voicing features (voiced versus voiceless) and place of articulation (bilabial, alveolar, and velar) [22,23], in consonance with other languages, for example, English [23–26]. VOT has been shown to be influenced by a variety of factors, including language-specific rules, phonetic environment, and prosody [20,27]. Moreover, BP language, the vowel environment, syllable stress, and syllable position may affect VOT [22,23,25]. Thus, these aspects should be considered when interpreting VOT data. Data from BP voiceless bilabial stop [p] productions have shown a VOT duration with a large natural range from 6.90 ms to 28.30 ms [22].

In addition, physiological factors can influence VOT measurements. General voice onset differences related to the place of articulation and voicing depend on numerous factors, such as aerodynamic forces, articulatory movements, and differences in the mass of articulators [20]. Therefore, disturbed phonation involving an imbalance of muscular tension and altered aerodynamic functions, vocal fold mass and stiffness, and articulatory movements or position all have the potential to impact VOT.

Studies carried out on healthy voices have shown that VOT duration in voiceless stop production decreases with increasing pitch [10,27]. The physiological hypothesis is that increased tension in the intrinsic laryngeal musculature related to higher f_0 leads to a decrease in glottal abduction amplitude, reducing VOT duration. In a recent study, Groll et al. [10] explored the relation between f_0 , self-reported vocal strain, and vocal effort in a group of sixteen vocally healthy speakers of both genders. The results confirmed that an increase in f_0 leads to a decrease in VOT duration in voiceless stop production embedded in a carrier phrase. However, these results were not confirmed for the characteristics of strain and vocal effort. In addition, despite SPL rising in both conditions (vocal effort and strain), there was no significant effect on VOT. The authors concluded that vocal effort and strain in typical speakers may be associated with individually different voice techniques and that a temporary increase in vocal effort may be associated with different underlying muscular adjustments as in patients with chronic vocal hyperfunction (VH). This reinforces

the hypothesis that VH is related to complex adjustments of intrinsic and extrinsic laryngeal muscles exhibiting recurrent patterns during a certain period of time [5].

1.2. Voice Onset Time in Vocal Hyperfunction

Few studies have applied VOT as an acoustic parameter to investigate voicing onset in patients with VH [28–31]. Three investigated patients with PVH associated with vocal nodules were compared with a control group in [28–30]. Two studies reported a shortening in VOT, but found no significant relation between PVH and VOT [28,30]. In opposition, the other of these works found elongated VOT [29].

Following the perspective that VOT should be shortened in VH, McKenna et al. (2020) [31] compared the voiceless stop production of two groups, 32 women with VH (21 with NPVH and 11 with PVH) and 32 vocally healthy women. In their study, VOT did not distinguish between the groups. A significantly shortened VOT was found only in a subset of women with VH who also had moderate perceptual dysphonia. The authors concluded that the increase in laryngeal muscle tension, as supposed in PVH conditions, may not impact VOT in a consistent way.

A relationship between VOT and VQ was consistently pointed out in two studies [30,31]. Colleti et al. (2022) [30] compared cepstral peak prominence (CPP) and VOT measurements (mean and variability) in stop voiceless production by children with and without vocal fold nodules during the production of Consensus Auditory–Perceptual Evaluation of Voice (CAPE-V) sentences. The authors found a strong positive correlation between CPP and the variability in VOT values for the vocal nodule group and concluded that the more dysphonic voices were, the more variable VOT measurements were.

It remains unclear how the VH condition influences VOT duration. Mehta et al. (2015) [32] described increases in laryngeal muscle tension in both NPVH and PVH, despite their different vocal fold states. In addition, structural laryngeal pathologies may imply differences in vocal fold mass and stiffness, which could impose adaptations in aerodynamic and myoelastic forces and delay voice onset. Findings that VOT decreases as f_0 increases in healthy voices support the argument that VOT should decrease when laryngeal muscle tension rises [10,33].

In this context, it is important to highlight that increased vocal amplitude (SPL) has been associated with higher laryngeal muscle tonus. Indeed, SPL has been shown to influence measurable VQ in several aspects, with improved acoustic measurement results for jitter, harmonics-to-noise-ratio (HNR), and cepstral peak prominence (CPPS) in both vocally healthy and disordered individuals [34,35] in higher speaking voice intensity levels. Even though it is possible that speaking SPL may affect VOT, this relation was not explored in any of the VOT studies addressing individuals with VH.

In this study, we aim to explore the potential of VOT as an indicator for VH and VQ. Specifically, we investigate whether VH condition and VQ impact the onset of voicing by addressing the followings research questions:

- (1) Does the VH condition influence VOT, f_0 , and speaking voice intensity?
- (2) Is there a relationship between vocal quality, VOT, f_0 , and speaking voice intensity?
- (3) Does the phonetic environment influence VOT, f_0 , and speaking voice intensity?

2. Materials and Methods

In a cross-sectional retrospective study, data from the cases of 31 adults with VH (21 women and 10 men) were selected from a clinical database to constitute the study group. This research was approved by the Ethics Committee of the Federal University of Bahia (letters n. 2.641.558/ICS and 2.761.949/HUPES).

2.1. Database

The original database consisted of cases of adults with voice disorders assessed at the Voice Care Outpatient Clinic of Edgar Santos University Hospital from January 2014 to December 2019. Each case was assigned a code to maintain anonymity. All information

about the patients was available in the form of electronic medical patient records. Laryngeal diagnosis was performed by an Otorhinolaryngologist (ORL) at the Ear, Nose, and Throat Ambulatory Outpatient Clinic of Edgar Santos University Hospital. Voice assessments were performed by a speech–language pathology student under the supervision of a speech–language pathology professor from the Federal University of Bahia Department in the Voice Care Outpatient Clinic of Edgar Santos University Hospital. Standard voice assessment consisted of: (i) a patient interview; (ii) a clinical voice examination, including head and postural description, laryngeal extrinsic musculature palpation, laryngeal position, and speech articulation assessment; (iii) vocal quality analysis by CAPE-V protocol [36]; (iv) maximum phonation time measurement; (v) voice recording of CAPE-V sentences, sustained vowel /a/, and spontaneous speech; and (vi) Voice Handicap Index-10 (VHI) [37] or Voice-Related Quality of Life (V-RQOL) [38] questionnaires. It is important to highlight that these data were collected for clinical purposes, and as such they represent an outpatient sample.

2.2. Patient Inclusion Criteria

Suitable cases were selected from institutional medical records and audio recording databases. The inclusion criteria were: (i) medical patient records containing a basic description of the case, including age, gender, laryngeal diagnosis, and voice evaluation; (ii) conclusive laryngeal diagnosis describing structural lesions consistent with phonotrauma or VH without structural laryngeal alteration [5]; and (iii) recording quality requirements, including a Signal-to-Noise-Ratio (SNR) of at least 25 dB [39] and spectrographic type 1 or 2 signals [40] in target syllable vowels.

Diagnosis Criteria of PVH and NPVH

The diagnosis of PVH and NPHV was based on laryngeal findings and patient-reported voice complaints during the interview, both documented in medical records. Laryngeal diagnostics included a visual assessment of laryngeal structures and function with the description of (i) structural lesions consistent with phonotrauma such as benign mass lesions (vocal nodules, polyp, polypoid degeneration, or granuloma), submucosal cyst, or reactive lesions for the PVH group and (ii) without structural laryngeal alteration consistent with pMTD for the NPVH group. VH complaints included signs and symptoms of vocal fatigue, strain, roughness, voice breaks, vocal limitation, increased vocal effort, and neck discomfort [6].

2.3. Description of Included Cases

The examined group consisted of 31 patients with VH, 9 patients with NPVH, and 22 patients with PVH. The patients' ages ranged between 27 to 77 years, with a mean of 46.6 years (± 1.6). The women group age range was 27 to 77, with a mean of 46.1 (± 13.7), and the men's group range was 31 to 65 years, with a mean of 47.5 (± 11.0).

The laryngeal pathologies associated with PVH had following distribution: cyst (32%); polypoid degeneration (23%); polyp (18%); vocal fold nodules (14%); and granuloma (14%). Table 1 summarizes the distribution of cases after VH condition by gender.

Table 1. Distribution of patients according to gender and vocal hyperfunction condition.

		Men (n)	Women (n)	Total (n)	%
Vocal Hyperfunction	NPVH	3	6	9	29
	PVH	7	15	22	71

2.4. Voice Recording Technique and Study Corpus

The audio database was compiled from clinical data recorded during the period of January 2014 to December 2019. All voice recordings were performed in the same place and in a sound-treated acoustic booth. Two different pieces of recording equipment were used during this period: (i) a desktop computer and (ii) a digital recorder. Computer recordings

were taken using a monoarticular headset with a unidirectional condenser-type digital microphone (Satellite AE-216, frequency response range 20–15 kHz, sensitivity 64 ± 3 dB) positioned at a 5 cm distance and a 45° angle from the mouth. Praat software [41] was used as an audio interface in a mono channel setting. For the cases with digital recorders, Zoom equipment (model H2n) was set at 90° MS, 4 to 6 mic gain, uncompressed wave, volume 40 to 60, and stereo channel. The recorder was placed at a distance of 15 cm and at a 45° angle from the mouth. The audio files were transferred from the digital recorder to the computer and stored.

All recordings used a 44 kHz sampling rate and 32-bit quantization in .wav audio format. Procedures to calibrate voice SPL were carried to for both types of equipment separately by applying a comparison method, as described in Sampaio et al. (2020) [35].

All voice recordings contained at least a sustained vowel [a], the six CAPE-V sentences adapted for Brazilian Portuguese [42], and a spontaneous speech sample. The CAPE-V sentences were presented to patients on a card, and they were instructed to read the sentences with habitual pitch and loudness. When a patient had difficulty reading, the task was accomplished by repetition.

Composition of Study Corpus

CAPE-V sentences were chosen for analysis because they are commonly used for speech assessment and provide speech samples with a controlled phonetic environment. Four samples of the voiceless bilabial stop [p] were selected for this analysis. The target tokens are displayed in Table 2.

Table 2. Target tokens from Brazilian Portuguese CAPE-V sentences in IPA and orthographic form, word, following vowel and syllable stress pattern.

Sentence	Word	Vowel	Stress
[ɛˈri.kə to.mˈoʊ sˈu.kʰ ɕi pˈe.rɐ ya.mˈɔ.rɐ] Erica tomou suco de pera e amora	/pˈe.ra/	[e]	Stressed
[pa. pˈaj tr ˈo.fi pi.pˈɔ.kɐ kˈɛ.tʃi] Papai trouxe pipoca quente	/pa.pˈaj/ /pi.pˈɔ.ka/ /pi.pˈɔ.ka/	[aj] [ɪ] [ɔ]	Unstressed Unstressed Stressed

Because the phonetic environment is expected to significantly affect acoustic measurements [24,39], two phonetic features were controlled in this corpus: (i) vowel or diphthong [e, ɪ, ɔ, aj] and (ii) syllable stress, i.e., stressed or unstressed.

For the purpose of analysis, an independent variable concerning the mode of speech task was created. As explained in item 2.4, the CAPE-V sentences could be performed by reading, preferable mode, or by repetition when the patient could not accomplish it by reading. The mode of delivery of speech task (reading versus repetition) was incorporated into the statistical model.

2.5. Perceptual Assessment

Even though the database included information about the clinical perceptual voice examination, this was not used in the present data. A perceptual assessment with CAPE-V sentences was performed using the patient recordings to ensure the homogeneity of voice judgments. Each audio stimulus was constructed with the two target CAPE-V sentences in the same sequence. Thirty-eight stimuli, one for each case, plus 22.5% repeated stimuli to test intra-rater reliability, were assessed by an experienced speech pathologist blind to the study purpose. All audio files were presented randomly through Alvin Experiment Control Software [43]. The perceptual analysis responses were registered directly in the Alvin interface, using a visual analogical scale (VAS) with 100 mm, following the instructions of the CAPE-V protocol [36]. Four voice characteristics were judged: overall severity of dysphonia (OS), roughness, breathiness, and strain. The respective answers were registered in a .txt file within the Alvin Software.

All measures were extracted automatically with a custom Praat script [46,47]. The syllable frame ([p] + vowel or diphthong) was considered for extraction of f_0 and SPL. To determine CV f_0 , the coefficient of variation was defined as the ratio of standard deviation to the mean ($CV = \sigma/\mu$) [48]. VOT was defined as the interval between the release of the burst and the first voicing pulse [21]. For analysis procedures, the results for VOT (ms), f_0

(Hz), and SPL (dB(A)) were exported to a spreadsheet. After that, calibrated SPL values and CV_{fo} (%) were calculated.

Table 3. Description of analysis settings in Praat and acoustic features of [p].

Display	Setting
Spectrogram	View range (Hz): 0.0 to 5.00 Window length (s): 0.005 Dynamic Range (dB): 40.0 View range (Hz): 75 to 500 Unit: Hertz
Pitch setting	Analysis method: Cross correlation Drawing method: Automatic
Formant tracking	Default setting
Intensity	Default setting
Window zoom to set voicing boundary	20 to 50 ms
[p] Acoustic Feature	Description *
Voiced closure interval (VDCLO)	The voiced portion of the stop closure
Voiceless closure interval (VLCLO)	The voiceless portion of the stop closure
Release (REL)	Release of the burst
Aspiration (ASP)	The aspiration after the burst

Note: * Definitions are described in Kang and Whalen [46].

An inspection of VOT measures showed one negative value, which means that in that particular sample the voicing started before the burst. This was considered to be an outlier, and was counted as a missing case in the statistical analysis. Moreover, one sample of the target phone [pi] had no voicing during the following vowel. Therefore, for this sample the parameters VOT, *fo*, and CV_{fo} data were counted as missing data in the analysis. In total, 3.2% of the total data (two samples) was excluded from the analysis.

2.7. Statistical Analysis

Statistical analysis was performed with SPSS Statistics (version 25) [49]. Shapiro–Wilk tests were applied to all four dependent variables (VOT, *fo*, CV_{fo}, and SPL) to investigate the normality of the data distribution. The results showed a normal distribution for *fo* ($W = 0.99, p = 0.47$), SPL ($W = 0.98, p = 0.32$), and VOT ($W = 0.99, p = 0.67$) and a non-normal distribution for CV_{fo} ($W = 0.84, p < 0.001$). Considering homogeneity of variance as indicated by the Levene statistics (LS), the variables *fo* ($LS = 0.33, p = 0.56$), SPL ($LS = 0.44, p = 0.50$), and VOT ($LS = 0.07, p = 0.78$) showed homogeneity, while CV_{fo} ($LS = 8.0, p < 0.001$) did not. After logarithmic transformation, CV_{fo} showed normal distribution ($W = 0.98, p = 0.12$) and homogeneity of variance ($LS = 0.71, p = 0.40$). Thereafter, all dependent variables were suitable for analysis by parametric statistical tests.

For the first and second aims, to determine the effects of VH condition and VQ on VOT, *fo*, and SPL, a multivariate analysis of variance (MANOVA) was applied. Two interactions were examined: (i) VH (two levels, NPVH and PVH) and (ii) VQ as represented by the OS (three levels, mild, moderate, and severe). Due to the inequality of samples between groups, Pillai's Trace was used to interpret the MANOVA results. The significance level (α) was set a priori to *p*-values less than 0.05 ($p < 0.05$). Squared partial curvilinear correlation (η^2_p) was used to interpret effect sizes [50]. Post hoc testing using the Bonferroni method was run for all combinations of interaction effects.

Thereafter, Spearman's rank correlation coefficient was applied to explore the relation between VOT, *fo*, SPL, and CV_{fo} with VQ, because the perceptual voice data (roughness, breathiness, and strain) were non-normally distributed. This analysis considered all three perceptual subcharacteristics of VQ, including roughness, breathiness, and strain, plus the OS. This analysis used numerical values of perceptual judgment (0 to 100) instead of categorical variables (none, mild, moderate, and severe).

For the third aim, in order to determine whether the phonetic environment affects VOT, *fo* (mean and CV), and SPL, a further MANOVA analysis was applied, with the following interactions: (i) syllable, i.e., following vowel (four levels, [e; I; ɔ and aj]); (ii) syllable stress (two levels, stress or unstressed); and (iii) mode of speech task (two levels, reading or repetition). Again, gender was included as a co-factor.

3. Results

3.1. Descriptive Results

The group was analyzed considering two main characteristics, namely, VH condition and VQ. The case distribution of OS by gender is described in Table 4. Descriptive data for dependent variables are reported in Table 5, split by gender. The mean VOT range for the whole group was 18.87 (± 0.72), and was distributed from 0 to 37 ms.

Table 4. Distribution of overall severity of dysphonia by gender.

Overall Severity of Dysphonia	Men (n)	Women (n)	Total (n)	%
Mild	8	11	19	61.29
Moderate	1	7	8	25.81
Severe	1	3	4	12.90
Total	10	21	31	100

Table 5. Descriptive results for VOT (ms), *fo* (Hz), SPL (dB(A)), and CV_*fo* (%), split by gender.

Gender		n	Mean	SD	Range	Minimum	Maximum
Men	VOT	40	19.39	8.18	37	0	37
	<i>fo</i>	40	134.74	26.07	103.0	78.0	180.0
	SPL	40	55.81	5.17	20.6	45.03	65.63
	CV_ <i>fo</i>	40	1.24	0.26	1.30	0.53	1.83
Women	VOT	83	18.62	7.93	36	0	36
	<i>fo</i>	83	185.07	39.32	200.0	80	281
	SPL	84	58.51	4.32	19.84	48.36	68.20
	CV_ <i>fo</i>	83	1.28	.342	1.80	.22	2.02

Abbreviations: *n* = number of included samples; SD = Standard Deviation; VOT = Voice Onset Time (ms); *fo* = fundamental frequency (Hz), CV_*fo* = Coefficient of variation of fundamental frequency (%), and SPL = sound level pressure (dB(A)).

3.2. Effects of VH Condition, OS, and Gender on VOT, *fo*, and SPL

3.2.1. VH Condition

VH condition (NPVH versus PVH) only affected CV_*fo* ($p = 0.02$, $\eta_p^2 = 0.04$), and did not affect the other investigated variables of VOT, *fo*, and SPL. The interaction of VH and OS significantly influenced *fo* ($p = 0.01$, $\eta_p^2 = 0.07$), even though VH and OS as isolated characteristics did not significantly affect *fo*. All of these results are summarized in detail in Table 6.

3.2.2. Vocal Quality

According to Table 6, OS had a highly significant influence on VOT, combined with a small effect size ($p \leq 0.001$, $\eta_p^2 = 0.09$). VOT values were greater as the degree of OS increased.

Results of the post hoc Bonferroni test showed that VOT discriminated mild voice deviation ($M = 16.67$) from moderate deviation ($M = 21.621$) ($p \leq 0.001$) and mild deviation ($M = 16.67$) from severe voice deviation ($M = 24.51$) ($p \leq 0.001$). Detailed results are available in Table 7.

3.2.3. Gender

Gender had a highly significant influence on both *fo* and SPL, with a moderate effect size for *fo* and a small effect size for SPL ($p \leq 0.001$, $\eta_p^2 = 0.30$ and $p = 0.01$, $\eta_p^2 = 0.05$,

($r = 0.29, p \leq 0.001$), breathiness ($r = 0.22, p \leq 0.001$), and strain ($r = 0.29, p \leq 0.001$). These results indicate longer VOT with more severe OS.

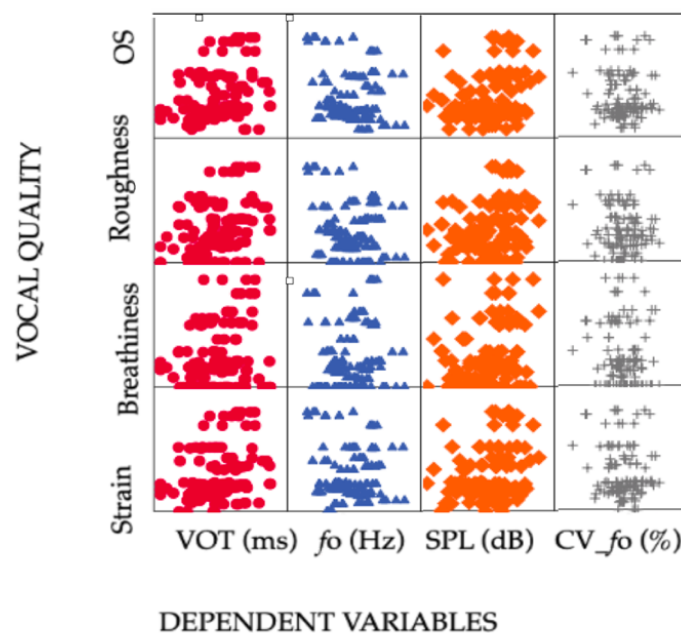


Figure 2. Scatterplot distribution of Voice Onset Time (ms) indicated as a red round symbol, fundamental frequency (f_0) indicated as a blue triangle, sound pressure level (SPL) indicated as an orange diamond, and fundamental frequency coefficient of variation (CV_{f_0} %) indicated as a grey cross, with the vocal quality parameters overall severity of dysphonia, roughness, breathiness, and strain.

Fundamental frequency showed a weak negative correlation with all perceptual VQ parameters, although the results were not significant: OS ($r = -0.11, p = 0.20$); roughness ($r = -0.08, p = 0.37$); breathiness ($r = 0.13, p = 0.15$); strain ($r = -0.02, p = 0.76$). In addition, f_0 showed a weak and non-significant correlation with SPL ($r = 0.15, p = 0.11$) and CV_{f_0} ($r = -0.08, p = 0.34$). Voice SPL demonstrated weakly positive and highly significant correlations with all perceptual VQ parameters: OS ($r = 0.24, p \leq 0.001$); roughness ($r = 0.26, p \leq 0.001$); breathiness ($r = 0.25, p \leq 0.001$); and strain ($r = 0.26, p \leq 0.001$). SPL had higher values for more deviant VQ.

3.4. Effects of Phonetic Environment on VOT, f_0 , and SPL

The phonetic characteristics vowel context [I, e, ɔ and ay], syllable stress (stressed or unstressed), and mode of speech task (reading or repetition) were investigated as independent variables that may affect VOT, f_0 , and SPL. None of the independent variables had an influence on VOT, f_0 , SPL, and CV_{f_0} . Moreover, the interaction of variables had no effect on the dependent variables.

As expected, gender influenced f_0 with a small effect size ($p \leq 0.001, \eta_p^2 = 0.33$), as well as SPL with a medium effect size ($p \leq 0.001, \eta_p^2 = 0.09$), while no influence was found for VOT ($p = 6.33, \eta_p^2 = 0.00$) and CV_{f_0} ($p = 0.60, \eta_p^2 = 0.00$).

4. Discussion

In the present study of adults with VH, Voice Onset Time was significantly affected by VQ. This was true for the OS as well as for each subcharacteristic (roughness, breathiness, and strain). In turn, VH condition and phonetic environment did not substantially influence VOT.

Deviations in perceptual voice onset are well-described characteristics of vocal dysfunction [51–53]; thus, VOT may have the potential to measure these objectively using

acoustic analysis. However, perceptual assessment results are systematically related to speaking SPL. Therefore, a larger clinical study in different age and pathology groups (stratified after PVH diagnosis), including speaking voice SPL as covariable, should explore how useful VOT is as a clinical indicator of voice onset dysfunction.

4.1. VOT Mean Duration

In the present work, VOT measurement results were affected by VQ. Our results for the VH group show a slightly longer VOT mean than those reported in literature, range between 6.90 ms to 28.30 ms for BP bilabial voiceless [22], though lower than found in one study [54]. Thus, the VOT values reported here are in the expected range for maintaining phonologic distinctions, which is essential for preserving speech intelligibility.

Comparing absolute VOT values between studies is highly challenging because this measure may be affected by phonetic context and individual conditions such as gender, age [24,39], and supposed pathophysiological conditions. In addition, perceptual dysphonia may occur in individuals who consider themselves to be vocally healthy. In this context, it is relevant to point out that this study did not aim to compare VOT data from a voice-disordered group with a control group. Nevertheless, it is reasonable to assume that our data indicate an elongation of VOT with increased dysphonia. This contradicts the hypothesis that VH may reduce VOT duration [28,31], and agrees with the findings reported by Marciniec [29].

4.2. Influence of VH Condition on VOT, *fo*, and SPL

This study was designed by mixing NPVH and PVH cases to investigate whether the two conditions of VH have different effects on VOT and further so-called traditional voice measures, including mean *fo*, SPL, and CV_*fo*. Our findings agree with the results of McKenna et al. [31] in that VH condition did not influence VOT systematically. In addition, there were no differences in *fo*, SPL, or CV_*fo* for the NPHV and PHV subgroups.

These results may be partly due to the heterogeneous characteristics of the VH sample, which contained different laryngeal pathologies for PVH and a comparatively low number of cases. Interestingly, the VH condition only affected *fo* when interacting with OS, despite none of the two significantly influencing in isolation *fo*. Further studies with a larger group of patients with identical phonotraumatic tissue lesions and equally distributed by gender would allow stratified analysis by gender, supporting a more detailed understanding of the interactions of VH, *fo*, and gender.

Previous reports have pointed out that PVH does not differentiate from typical voices for average *fo* and SPL [55–57], supporting the view that patients with VH use different physiological strategies to maintain a functional voice. Therefore, other approaches for *fo* and SPL must be implemented in order to better describe VH. Several studies have shown that RFF can indicate the condition of VH and track the treatment changes [8]. As RFF is a measure of *fo* related to the onset of voicing, future studies associating RFF with VOT could add more information on VH behavior.

4.3. VQ Is Correlated with VOT

Two conditions of VH were analyzed in this study: one group with PHV associated with five different laryngeal pathologies and one group with NPHV. All VH conditions have examples of three-grade deviant VQ (mild, moderate, and severe), despite not being equally distributed by gender.

In our data, all VQ characteristics correlate with VOT, which is in consonance with similar studies [30,31]. VQ can range from not deviant to severely deviant in patients with VH, and is not a key determinant to distinguish patients in the NPVH group between those from the PVH group. In other words, the presence or absence of a phonotraumatic structural lesion is insufficient to indicate the degree of vocal deviation. Furthermore, it is essential to consider that vocal tract adjustments are critical to vocal output and the phenomenon of dysphonia.

Based on our findings, we conclude that voicing onset, even as measured objectively, seems to play an important role in the perception of VQ deviation. From a broad perspective, our findings show that the more deviant the VQ is, the longer the VOT duration. Furthermore, the VOT Confidence Interval, i.e., the data spread, increased as the OS became more severe. All vocal parameters composing VQ, namely, roughness, breathiness, and strain, were significantly correlated with VOT, while vocal strain and roughness had a highly significant association. This endorses the assumption that increased tension in the vocal mechanism, as represented by audible strain and roughness (increased adduction), impacts the voicing onset and perceptual VQ.

4.4. Influence of Phonetic Environment

One main methodological concern of this study was using speech material available in clinical voice recordings. Taking advantage of recording procedures already widely used in voice clinics may allow an improvement of voice diagnostics without adding more speech tasks, thereby risking overloading the patient. Furthermore, as these data are from a clinical database, they represent an investigation of realistic materials. The CAPE-V sentences are widely applied, and have the advantage of providing a standardized phonetic speech environment despite not being phonetically balanced. In this way, it is possible to guarantee the constancy and reproducibility of the phonetic context.

The corpus proposed in this study is composed of the voiceless bilabial stop [p], with three combinations of vowels and one gliding vowel [e, I, ɔ and aj], two combinations of stress (stressed and unstressed), and two modes of speech task (repetition and reading). Although BP studies claim that the phonetic environment may affect VOT measurements [22,23,25], we did not find a relation with a vowel after [p], syllable stress, or mode of speech task in the present study.

Considering the individuals' characteristics in the phonetic environment, gender showed a strong relationship with both mean *f*₀ and SPL, which is in alignment with the literature [20]. Xuanda [58] pointed out that VOT tends to be reduced in elderly people. Thus, heterogeneity between the groups in terms of age may have affected the present acoustic measurements, which may have partially masked potential phonetic context effects. Due to the comparatively small sample size, we did not stratify by age or different combinations of phonetic environments; this would call for an expanded study with more patients of different ages, including a larger variety of samples.

4.5. Gender Effects

In the present work, both gender groups were investigated. Thus, as far as we know, this is the first work systematically observing VOT in men with VH. In fact, despite men and women having differences in physiology related to the size of the vocal tract and vocal folds that could potentially influence the voicing onset, there are no reliable indicators in the literature to indicate whether VOT is gender sensitive. As expected, gender strongly influenced both *f*₀ and SPL for the case characteristics (VH condition and VQ) and the phonetic environment characteristics (vowel, syllable stress, and mode of speech task). Therefore, it is important to consider gender as a variable in voice analysis for numerous variables. However, future studies should investigate a larger sample of vocally healthy and voice-disordered women and men while applying gender as a dependent variable in order to verify whether VOT is genuinely independent of gender-related physiological differences and behavior.

4.6. Clinical Relevance and Future Directions

Beyond the language and phonetic conditions, VOT is speaker-specific and varies over time [20,58]. Even in typical speech, there are many gaps in understanding the onset of voicing and its complex relationship with the individuality of speakers and universal principles. Voice disorders represent a challenging situation regarding the complex interaction of multiple dimensions. Further research is necessary in order to understand the short-term

fluctuations in VOT and how it establishes a long-term changing trend in pathological voice mechanisms.

Voice quality has been addressed in acoustic analysis mainly by *fo*, SPL control, harmonicity, and noise measurements. However, in the present work VOT showed the potential to provide objective, and as such universally replicable information about the onset of voicing with VQ. Because a disturbed voice onset is considered one of the main characteristics of a dysphonic voice, this adds a new perspective and dimension to objective voice analysis [59,60].

5. Conclusions

The present work aimed to explore the potential of VOT as an indicator of VH condition (NPVH or PVH) and VQ. Productions of [p] in CAPE-V sentences were analyzed, and the effect of VH condition and VQ were explored. VOT was not associated with the VH condition, while it was associated with the OS and had a high degree of relation to perceptual roughness and strain. Considering the phonetic environment factors, vowel context, syllable stress, and mode of speech task had no influence on the dependent variables. Because deviations in perceptual voice onset are well-described characteristics of vocal dysfunction, VOT shows the potential to objectively characterize the onset of voicing related to vocal quality. These results should be confirmed in a larger clinical study of women and men in different age groups and with larger pathology groups stratified according to PVH diagnosis.

Author Contributions: Conceptualization, M.F.d.P.S.; Data curation, M.S.; Investigation, M.F.d.P.S.; Methodology, M.F.d.P.S. and M.B.-B.; Supervision, M.B.-B.; Writing—original draft, M.F.d.P.S.; Writing—review and editing, M.S. and M.B.-B. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: The present study is part of an ongoing larger project entitled “Studying the Behavior of Acoustic Measures of the Praat Program in Voice Evaluation” approved by the Ethics Committee of the Federal University of Bahia (letters n. 2.641.558/ICS and 2.761.949/HUPES).

Informed Consent Statement: Written informed consent has been obtained from the patient(s) to publish the results of this study.

Acknowledgments: We gratefully acknowledge all patients, students, and professors that contributed in one way or another to the database used in this study. In addition, a special thanks to José Joaquim Araújo Filho who contributed to editing the paper.

Conflicts of Interest: The authors have no conflict of interest to disclose.

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