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VOICE ONSET TIME IN CHILDREN WITH AND WITHOUT VOCAL FOLD NODULES

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ABSTRACT

Purpose: Voice onset time (VOT) of voiceless consonants provides information on the coordination of the vocal and articulatory systems. This study examined whether vocal-articulatory coordination is affected by the presence of vocal fold nodules (VFN) in children.

Methods: The voices of children with VFN (6-12 years) and age- and gender-matched vocally healthy controls were examined. VOT was calculated as the time between the voiceless stop consonant burst and the vocal onset of the vowel. Measures of the average VOT and VOT variability, defined as the coefficient of variation, were calculated. The acoustic measure of dysphonia, cepstral peak prominence (CPP), was also calculated. CPP provides information about the overall periodicity of the signal, with more dysphonic voices having lower CPP values.

Results: There were no significant differences in either average VOT or VOT variability between the VFN and control groups. VOT variability and average VOT were both significantly predicted by the interaction between Group and CPP. There was a significant negative correlation between CPP and VOT variability in the VFN group, but no significant relationship was found in the control group.

Conclusion: Unlike previous studies with adults, there were no group differences in average VOT or VOT variability in the current study. However, children with VFN who were more dysphonic had increased VOT variability, suggestive of a relationship between dysphonia severity and control of vocal onset during speech production.

INTRODUCTION

Vocal fold nodules (VFN) are the most common cause of dysphonia in children (Akif Kiliç et al., 2004; Ongkasuwan & Friedman, 2013; Shah et al., 2005; Shearer, 1972; Tavares et al., 2011). Children with VFN may exhibit phonotraumatic vocal behaviors, that can occur in situations conducive to yelling, such as participating in sports or speaking in noisy environments. Additionally, they may also demonstrate inefficient or inappropriate vocal use (i.e., misuse), such as speaking at a pitch that is too high or too low or using increased vocal strain (Hillman et al., 1989, 2020). The etiology of VFN can also be exacerbated by conditions such as laryngopharyngeal reflux, allergies, and nasal obstruction, which are all common in children (Bhattacharyya, 2015; Block & Brodsky, 2007; De Bodt et al., 2007; Martins et al., 2012; Özçelik Korkmaz & Tüzüner, 2020). Treatment for dysphonia is essential as chronic dysphonia can negatively impact a child's voice use, behaviors, school performance, social participation, and other aspects of health and daily life (Carroll et al., 2013; Connor et al., 2008; Verduyckt et al., 2011).

Although children and adults both develop VFN, previous research has pointed to significant differences in VFN presentation between children and adults. Unlike VFN in adults, which are more commonly found in women, VFN in children are more commonly found in male children, especially in those around school-age (6-12 years) (Akif Kiliç et al., 2004; Coyle et al., 2001; De Bodt et al., 2007; Dobres et al., 1990). Children with VFN have differences in respiratory and laryngeal functions compared to adults with VFN (Lohscheller & Eysholdt, 2008; Patel et al., 2016; Sapienza & Stathopoulos, 1994; Yamauchi et al., 2016). Acoustic measures of fundamental frequency (f_o) transitions into and out of voiceless consonants are significantly different in adults with and without phonotraumatic (e.g., vocal fold nodules) voice disorders (Heller Murray et al., 2017; Stepp et al., 2010), yet these same measures are not different in children with and without phonotraumatic voice disorders (Heller Murray et al., 2020). Furthermore, adults with voice disorders have reduced auditory discrimination abilities compared to adults without voice disorders (Abur et al., 2021), while children with and without voice disorders have comparable auditory discrimination abilities (Heller Murray et al., 2019). The differences between children with VFN and adults may be partially attributed to the significant structural differences in the laryngeal mechanism between children and adults. The vocal folds of children are smaller than those of adults, with differences in their microstructure, and an approximately equal membranous-to-cartilaginous ratio in infancy that changes over development so the membranous portion becomes more dominant (Boseley & Hartnick, 2006; Hammond et al., 1998, 2000; Hirano et al., 1983; Rogers et al., 2014; Sato et al., 2001, 2006; Schweinfurth & Thibeault, 2008). Furthermore, the mature three-layer vocal fold structure does not fully emerge until around seven years, with differentiation initially occurring between one and four years of age (Hartnick et al., 2005; Hirano et al., 1983; Ishii et al., 2000; Sato et al., 2001). These structural changes contribute to the differences in vibratory motions as well as abduction and adduction behavior in children compared to adults (Döllinger et al., 2012; Patel et al., 2012, 2014a, 2014b, 2015), further providing evidence of differences in the vocal system between adults and children. In addition to these changes in the vocal system, children also undergo significant changes in their articulatory systems (Kent, 1976; Koenig, 2000;

Vorperian et al., 2009; Vorperian & Kent, 2007). In typical children, maintaining intelligible speech requires adapting to the developmental changes in both systems (Figure 1, blue arrow). Children with VFN also adapt to these typical developmental changes, however, they also have an additional task of adapting to any changes that occur in either system due to the presence of a voice disorder (Figure 1, red arrow). Thus, to fully understand the impact of VFN in children, changes in both the developing vocal and articulatory systems must be considered.

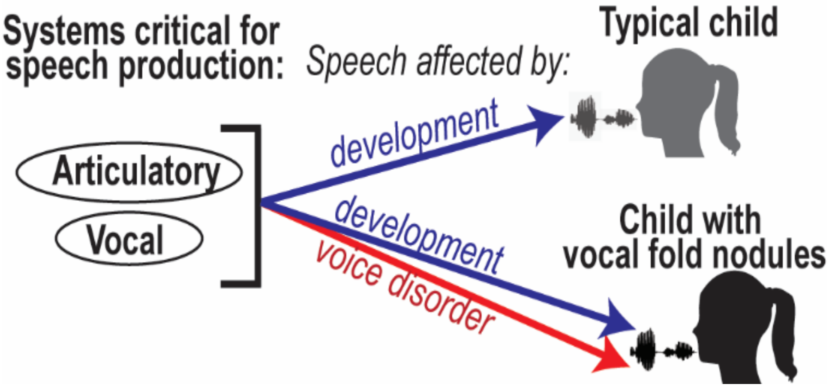

Figure 1.A schematic depicting that both development (blue arrow) and a voice disorder (red arrow) impact speech production in children with vocal fold nodules.

One method of examining the coordination of the vocal and articulatory systems during speech is the measurement of voice onset time (VOT). VOT is the time between the release of the stop consonant and the initiation of the subsequent vowel (Lisker & Abramson, 1964, 1967). Coordination between these two systems is especially crucial for producing voiceless stops, which require the vocal folds to remain open during the stop production with subsequent closure to support phonation during the vowel. In English-speaking adults, VOT is an acoustic temporal cue used by listeners to determine whether a consonant is voiced or voiceless, as voiced productions have a shorter VOT than voiceless productions (Lisker & Abramson, 1964, 1967). However, this clear distinction between voiced and voiceless productions is not always present in children. For example, in children 9-18-month-olds, there is minimal to no distinction between the VOTs of voiced and voiceless cognates. This distinction emerges around 18 -28 months of age when production accuracy increases and production range decreases (Barton & Macken, 1980; Hitchcock & Koenig, 2013). Children's VOTs reach adult-like averages around six years of age, although increased production variability is present until 8 -11 years of age when this variability reaches adult-like levels (Eguchi & Hirsh, 1969; Kent, 1976; Kewley-Port & Preston, 1974; S. Whiteside et al., 2003; Yu et al., 2014). A key factor that remains unknown is whether a structural difference in the developing vocal system (i.e., the presence of VFN) impacts the relationship between the vocal and articulatory systems during development.

Only a few studies have examined VOT in individuals with dysphonia. McKenna and colleagues (2020) found that adults with vocal hyperfunction exhibited more variable VOTs than a cohort of age- and gender-matched vocally healthy individuals. Furthermore, VOT variability was related to dysphonia severity, with increased dysphonia severity associated with increased VOT variability (McKenna et al., 2020). Heller Murray and Chao (2021) examined the relationship between VOT variability and dysphonia in children. Although no relationship was found between VOT variability and dysphonia, there was a correlation between dysphonia severity and f_o variability (Heller Murray & Chao, 2021). Importantly, this work did not know the voice disorder status of the children, and additional work is needed to examine this relationship in children diagnosed with voice disorders. The current study was a secondary analysis of data collected from age- and gender-matched children with and without VFN between 6 and 12 years of age. This data was initially collected for another study examining voice in children with and without VFN (Heller Murray et al., 2020) in which vocalic onset and offset f_o were examined. The previous study was designed to examine a more commonly used measure of vocal hyperfunction in individuals with voice disorders (Heller Murray et al., 2016, 2017; Kapsner-Smith et al., 2022; Roy et al., 2016; Stepp et al., 2010, 2011). The current work utilized speech samples from the same participants to examine a distinct measurement, VOT. This temporal measurement allows a novel look at the coordination of the voice and speech system in children with VFN.

The following research questions examined group differences in the measures of interest, average VOT and VOT variability:

Q1: Does average VOT or VOT variability vary between children with and without VFN?

Q2: Does the relationship between VOT variability and CPP or the relationship between average VOT and CPP vary between children with and without VFN?

METHODS

Participants

Twenty-eight children with vocal fold nodules (average 9.1 years, 13 female, 15 male) were selected from a clinical database at Boston Children’s Hospital Data for the original study (Heller Murray et al., 2020); the same participants were examined for the current analysis. Participants with VFN were retrospectively selected from the clinical database with the following inclusion criteria: (1) between 6.0 and 12.5 years of age; (2) had a primary diagnosis of bilateral vocal fold nodules made during a flexible laryngoscopic evaluation by an Otolaryngologist at Boston Children's Hospital who received specialized fellowship training in pediatrics; (3) no prior voice therapy history; (4) received an overall voice severity score greater than or equal to 25 rated on the Consensus Auditory-Perceptual Evaluation of Voice (CAPE-V) (Kempster et al., 2009) determined by a certified speech-language pathologist during the initial clinical evaluation; (5) no history of other speech, language, or hearing concerns noted during evaluation; (6) usable, high-quality voice recordings were obtained during the initial clinical evaluation; and (7) accents were representative of a fluent English speaker from the northeast region. Boston Children's Hospital Institutional Review Board approved the retrospective search for the original study and permitted reliance on the Boston University Institutional Review Board for the full study review (Heller Murray et al., 2020).

A control group of 28 children without VFN (average 8.9 years, 13 female, 15 male) were recruited from Boston and its surrounding communities for the original study. Children without VFN were recruited after selecting children with VFN from the Boston Children's Hospital clinical database. Thus, the children without VFN were recruited to be age- and gender-matched to the children with VFN. Participants spoke English as their primary language, had no history of a voice disorder per parental report, and had not received speech or language therapy within the previous year. A speech-language pathologist confirmed that vocal quality was within the normal range for all children without VFN. Children aged 7;0 and older provided verbal assent and dissent from children under 7;0 was respected, while guardians provided written consent. The original study was approved by Boston University Institutional Review Board (Heller Murray et al., 2020).

Recording Procedures

All recordings were completed in a sound-treated room. Recordings from children with VFN were completed during clinical evaluation with the Computerized Speech Lab (Pentax Medical), with a 32.0 kHz sampling rate and a 16-bit resolution. Information about the microphone used during recordings was not available. Recordings from the control group were conducted with a dynamic headset microphone (model WH20XLR) and acquired with a MOTU Ultralite mk3 hybrid soundcard (MOTU, Cambridge, MA, USA), sampled at 44.1 kHz with a 16-bit resolution. An independent sample t-test indicated there was no significant difference in signal-to-noise ratio of the background noise to the speech production between speech samples collected from the children with VFN (mean (M) = 28.14 dB) or the control group (M = 28.34 dB, (t(53) = -0.11, p = .91).

Children repeated each of the six CAPE-V sentences one to three times. The number of repetitions varied based on clinician preference during the initial recording, primarily due to reasons such as audible mistakes or confusion by the child on the speech task. Four voiceless consonants were selected for VOT analysis; only correct productions of the voiceless consonants were analyzed (Table 1). Consistent with previous studies that optimized the identification of the first vocalic cycle (e.g., Heller Murray et al., 2020;

Lien & Stepp, 2014), the acoustic samples were low-pass filtered using a fifth-order Butterworth filter. A cutoff value of 680 Hz was selected for the filter, as it was 100 Hz higher than the highest f_o measured in the sample. This filtering aimed to reduce extraneous noise from the vocal tract and environment, thus making the vocal cycles easier to identify.

Table 1. Stimuli Selected for VOT analysis

CAPE-V Sentences	Word	Vocal onset analyzed
The blue spot is on the key again.	key	/ki/
Peter will keep at the peak.	Peter	/pi/
	keep	/ki/
	peak	/pi/

Data Processing and Acoustic Analysis

The burst of the stop consonant (VOT start) and the first vocalic cycle (VOT end) were manually identified in Praat for each VOT instance (Boersma & Weenick, 2019) (Figure 2). The stop consonant burst was identified in the unfiltered signal and marked at the zero-crossing directly before a large change in the waveform. This selection was confirmed by the presence of a dark vertical band in the spectrogram. The first vocal cycle was identified in the filtered waveform, using the voicing bar in the spectrogram to support the selection. Finally, the onset and offset of the target sentence were marked to determine the total sentence length. All marked boundaries were exported for analysis to excel and JMP (SAS Institute, 2019).

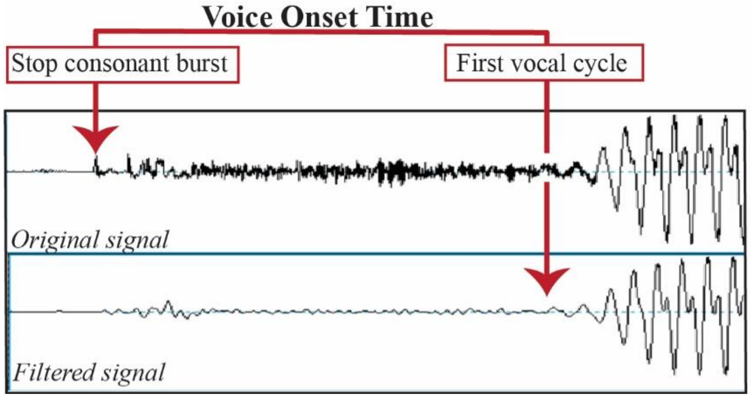

Figure 2. Example of the original signal (top) and filtered signal (bottom). Red arrows indicate the start of the voice onset time (stop consonant burst) and the end of the voice onset time (first vocal cycle).

Cepstral peak prominence (CPP) was calculated in Praat (Boersma & Weenick, 2019). CPP is the current recommendation for acoustic measurement of dysphonia (Patel et al., 2018), and relationships between CPP and dysphonia have been found in both adult and pediatric populations (e.g., Esen Aydinli et al., 2019; Heman-Ackah et al., 2002; Murton et al., 2020; Sauder et al., 2017). The measure of CPP is calculated in the cepstral domain and provides a measure of how high the cepstral peak (associated with the fundamental period) emerges from the cepstral noise (J. Hillenbrand et al., 1994; James Hillenbrand & Houde, 1996). A signal with a low CPP value, as seen in dysphonic voices, is less differentiated from the remainder of the vocal noise. The current work calculated CPP using a Praat plugin that measured CPP after removing the unvoiced and silent periods. Full details of this open-source plugin can be found here (Heller Murray et al., 2022). The current article used a silence threshold of 0.03 and a voicing threshold of 0.3 to find voiced periods of speech, and found CPP within the peak search range of 60-

500 Hz using a ‘Straight’ trendline and a ‘Robust’ fit method (Boersma & Weenick, 2019)

Data Analysis

Prior to data analysis, instances were removed if the VOT was greater than 200 ms (n = 4 instances) or if there was an audible elongation consistent with vocal play (n = 1 instance). We were interested in examining variation in typical speech production patterns without examining edge cases more indicative of extreme productions; therefore, these instances were considered outliers. Furthermore, 4 participants with VFN were removed from the analyses because they had less than 4 usable VOT values, resulting in a final grouping of 24 included participants with VFN and 28 included control participants. As VOT identification was a manual process, reliability measures were calculated first to ensure the results of VOT analyses could be interpretable. The first author (LC) repeated VOT analysis on 15% of the samples, and the senior author (EHM) completed VOT analysis on the same samples. Intraclass correlation coefficients (ICC) were calculated for interrater and intrarater reliability metrics (Koo & Li, 2016). Excellent reliability was found for both interrater (ICC = 0.94) and intrarater (ICC = 0.98) reliability measures.

Prior to all analyses, the distribution of each variable was tested for normality with a Shapiro-Wilk test. Variables that were not normally distributed were subsequently log-transformed before analysis. To confirm the different intentions behind the data collection (clinical evaluations versus research study) did not impact the number of VOTs used for analysis, an independent sample t-test examined the number of usable VOT instances in each group. Since CPP was a factor of interest in our research question, we wanted to confirm that other confounding variables did not significantly impact CPP. We specifically focused on vocal pitch and age, as previous work has shown they can be related to CPP (Brockmann-Bauser et al., 2021; Demirci et al., 2021; Infusino et al., 2015; Kent et al., 2021; Sampaio et al., 2020). A linear regression was conducted to examine whether Pitch or Age had a significant effect on the outcome of CPP. We did not anticipate that this linear regression would be significant, as CPP is primarily impacted by these factors in studies with wider age ranges with more extreme changes in pitch (Brockmann-Bauser et al., 2021; Demirci et al., 2021; Infusino et al., 2015; Kent et al., 2021; Sampaio et al., 2020)

The statistical analyses were selected to examine the two primary research questions: 1) Does average VOT or VOT variability vary between children with and without VFN? And 2) Does the relationship between average VOT and CPP or the relationship between VOT variability and CPP vary between children with and without VFN? Two linear regressions were calculated, one with the outcome of average VOT (model 1) and one with the outcome of VOT variability (model 2). Predictors of each model included Group, Age, CPP, Sentence Length, and Gender, as well the interaction of Group x CPP and Group x Sentence Length. The primary predictor of interest for the first research question was the main effect Group (VFN, control), while the interaction of Group x CPP was of primary interest for the second research question. Age and sentence length were also included as covariates in the models, as both variables can significantly impact VOT (Hitchcock & Koenig, 2013; Kent, 1976; Kessinger & Blumstein, 1998; Koenig, 2001; Macken & Barton, 1980; Volaitis & Miller, 1992; S. Whiteside &

Marshall, 2001; S. P. Whiteside et al., 2004; Yu et al., 2014, 2015; Zlatin & Koenigsknecht, 1976). The interaction of Group x sentence length was also included to account for any potential group differences (e.g., if one group always spoke faster). Any significant Group x CPP interactions were examined further with Pearson's correlations to evaluate the relationship between CPP and the outcome variable within each group.

RESULTS

Descriptive statistics for each group are outlined in Table 2 for the 28 included control subjects and the 24 included VFN subjects. There were no significant group differences in number of usable VOT instances (*t* (50) = 1.62, *p* = .11). Additionally, there was no significant main effect of pitch (β = -0.009, *p* = .56) or Age (β = -0.102, *p* = .55) on CPP.

Table 2. Descriptive statistics for included participants with usable VOT values

	Control Mean (stdev)	VFN Mean (stdev)
VOT average (milliseconds)	75.41 (17.0)	77.44 (21.17)
VOT variability (coefficient of variation)	0.35 (0.13)	0.34 (0.17)
CPP (decibels)	11.19 (1.71)	9.02 (1.74)
Number of usable VOTs	7.29 (1.41)	6.41 (2.39)
Sentence length (seconds)	2.07 (0.47)	2.18 (0.36)
Pitch (hertz)	267.95 (25.36)	262.95 (31.09)

Shapiro-Wilk tests indicated that distributions for VOT variability (W = 0.93, *p* = .005) and average sentence length (W = 0.87, *p* < .001) deviated from normal and thus were log-transformed. The first linear regression examining the outcome of the average VOT model was significant (R^2 = 0.35, *p* = .006), with average VOT significantly predicted by the main effect of sentence length (β = 0.06, *p* =.002), and the interaction of Group x CPP

(β = -0.003, p = .02). The second linear regression examining the outcome of VOT variability was also significant (R^2 = 0.30, p = .02), with VOT variability significantly predicted by the main effect of CPP (β = -0.07, p = .04) and the interaction between Group x CPP (β = 0.07, p = .02).

To further examine the interaction between Group x CPP for both VOT average and VOT variability, correlational analyses were conducted within each group. There was a significant negative correlation (r =-0.60, p = .002) between CPP and VOT variability within the VFN group, yet no correlation was noted for the control group (r =0.04, p = .85, Figure 3). There was no significant correlation between CPP and average VOT for either group (both $p >$ .05, Figure 3).

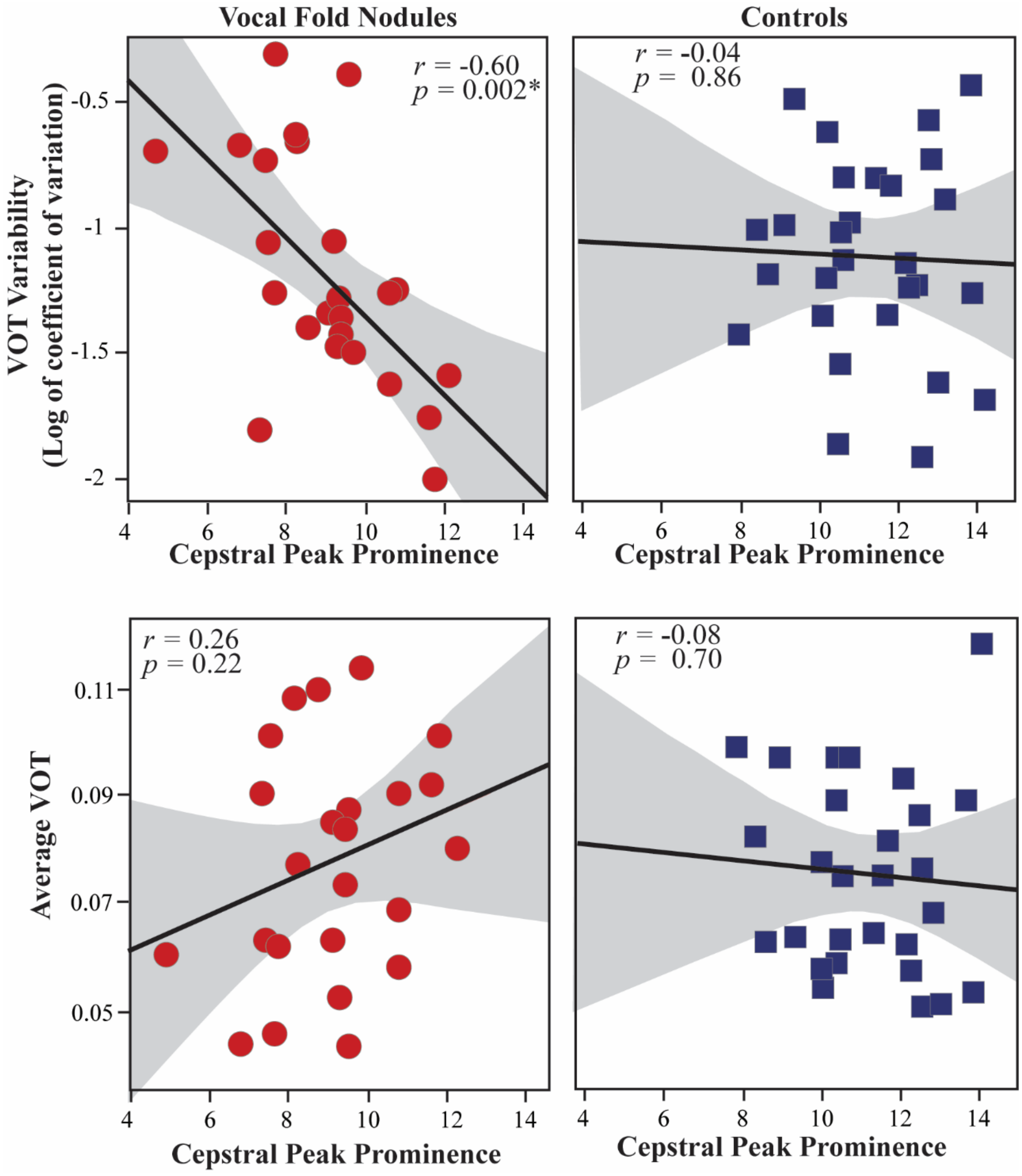

Figure 3. Figure 3. Relationships between voice onset time (VOT) variability and cepstral peak prominence (top row) and average VOT and cepstral peak prominence (bottom row). Children with vocal fold nodules had a significant negative correlation between cepstral peak prominence and VOT variability (top left, red circles). No other significant relationships were found. Solid black lines and grey shaded area indicate fit and 95% confidence intervals.

DISCUSSION

Research on children with VFN primarily focuses on voice and vocal outcomes. However, children do not use their voices in isolation during speech production. Rather, intelligible speech production requires children to coordinate their developing vocal and articulatory systems. Therefore, this study examined a naturally occurring segment of speech production that relies on vocal and articulatory coordination, VOTs of voiceless stop productions.

VOT variability

There was no significant difference in VOT variability between the VFN and Control groups. However, VOT variability was significantly predicted by the interaction of group and CPP. Further analysis within each group was conducted. A significant relationship was found in the VFN group, with increased dysphonia associated with increased VOT variability. No relationship was found between VOT variability and CPP in the control group. The current work suggests that children with VFN who display decreased periodicity (e.g., decreased CPP) also have increased variability of vocal control during speech production. We propose that one potential explanation for this relationship is the presence of vocal fold nodules interrupts the typical development of the vocal motor control system. This could make vocal fold movements less reliable, resulting in children with VFN being less likely to monitor them auditorily during speech (e.g., less likely to focus on changes in pitch and pitch variability) . If vocal motor control is related to the severity of the vocal deviation, this reduced reliability of vocal fold movements and decreased auditory monitoring during speech production could be more severe in children with greater dysphonia. However, this proposed idea requires additional studies designed to more directly address whether there are differences in vocal motor control in children with VFN, and whether these potential differences are impacted by factors such as the size of the VFN or the age of VFN onset.

Another potential explanation is that decreased motor control (e.g., increased VOT variability) is one of the factors causing phonotraumtic vocal behaviors to persist. The presence of the VFN can increase breathiness, as the VFN becomes the initial point of contact during phonation, leading to anterior and posterior escape of air (Simpson & Rosen, 2008; Sodersten & Lindestad, 1990). Children may also find it difficult to build up adequate subglottic pressure leading to the implementation of phonotraumatic behaviors (e.g., strain, increased muscle tension) to phonate. This vocal behavior leads to additional vocal misuse, further exacerbating the already present VFN (Galindo et al., 2017; Hillman et al., 1989, 2020). These maladaptive compensatory strategies children might employ may be more severe in children with increased dysphonia. Thus, the increased use of these phonotraumatic strategies may make all vocal production more variable, including the vocal control required for speech. Whether the changes in vocal motor control are in response to VFN or contribute to their persistence, it would be beneficial for clinicians to know if children are less attuned to their vocal motor system. Learning to control the vocal system is a key component in many direct therapy tasks (Van Stan et al., 2015; Verdolini Abbott, 2013) and thus understanding any potential deficits in vocal motor control could influence task selection. Additional work is needed explore this relationship between voice and speech motor control in children with VFN

Findings from the current study on the relationship between dysphonia and VOT variability are consistent with those of a previous study examining adults with hyperfunctional voice disorders (McKenna et al., 2020). However, unlike the current study, McKenna and colleagues noted that adults with voice disorders had increased VOT variability compared with gender- and age-matched vocally healthy peers (McKenna et al., 2020). The authors suggested this group difference may be related to the disordered vocal motor control hypothesized to be one of the causes of vocal hyperfunction development (Hillman et al., 2020; McKenna et al., 2020; Stepp et al., 2017). One key element of this hypothesis is that accurate auditory perception is needed to detect and correct vocal feedback errors, which is a key element of vocal motor control. Abur and colleagues found that adults with vocal hyperfunction have decreased auditory discrimination abilities (Abur et al., 2021), which may result in larger auditory target ranges and contribute to increased VOT variability in adults (McKenna et al., 2020). However, prior research suggests that children with VFN have comparable vocal discrimination abilities to age and gender-matched peers with typical voices (Heller Murray et al., 2019). As auditory-discrimination deficits do not appear to be present in children with VFN, this may explain why the current study did not find a group difference in VOT variability. Heller Murray and colleagues did note that younger children had poorer pitch discrimination abilities than older children. Moreover, older children continued to have poorer pitch discrimination abilities than adults (Heller

Murray et al., 2019). Further exploration into auditory discrimination deficits and vocal variability within the dysphonic pediatric population across different ages may be warranted. Additional work is also needed to examine if children with VFN perceive their vocal differences as ‘errors’ that require correction. Most adults who are their own primary caretakers will seek a professional evaluation if a change in their voice occurs. However, children are not their main caretakers and rely heavily on external sources to monitor changes in their behavior, health, and safety. Children referred to a professional for dysphonia are frequently brought in because someone external, such as a caregiver, has noticed a change in their vocal quality (Braden et al., 2018). Although research has shown that children are generally aware of their voice (Connor et al., 2008), further work is needed to determine children’s abilities to detect smaller changes in their own vocal quality.

Average VOT

There was no significant difference in average VOT values between children with and without VFN. Values for both groups were within the ranges found in previous work with typical children, with an average VOT range of 65 – 90 ms and coefficient of variation values between 0.18 – 0.34 (Kent, 1976; Koenig, 2001; S. Whiteside & Marshall, 2001; S. P. Whiteside et al., 2004; Yu et al., 2014, 2015; Zlatin & Koenigsknecht, 1976). Ideally, VOT measurements should be analyzed within phonemes, as normative data for VOT measurements differ by phoneme (Abramson & Whalen, 2017). However, this was not possible with the current study design; therefore, this work focused on two voiceless phonemes (/p/, /k/). Although there were not enough instances to examine any potential average or variability differences between these phonemes, both groups examined produced the same stimuli. Therefore, phoneme differences are unlikely to contribute to any group differences. Future work should include prospective data collection with a larger number of phonemes to examine nuances not captured in the current work.

Although there was no group difference in average VOT, there was a significant interaction between Group and CPP. The interaction suggested that individuals in the VFN group with decreased CPP had shorter average VOTs. However, further examination of this relationship in each group did not reach significance. Upon initial visual evaluation of this relationship, the VFN group appears to have greater between-subject variability. Therefore, the current sample size may have been underpowered to examine this relationship. Subsequent work should examine a larger group to elucidate this relationship fully. Another possible explanation is the strong relationship between average VOT and sentence length may have masked other findings. Sentence length measurements provide information about speech rate, which has been shown to influence VOT values of voiceless productions (Kessinger & Blumstein, 1998; Volaitis & Miller, 1992). Similar to these earlier studies, this current study demonstrated that shorter sentences (ostensibly spoken at a faster rate) were associated with decreased VOT. As speech rate was not controlled or experimentally tested in this retrospective design, future studies with controlled speech rates are needed to fully determine the relationship between average VOT and CPP in this population.

Cepstral peak prominence

Increased dysphonia was measured using the acoustic measure of CPP, which provides information on the harmonic structure related to the periodicity of the vocal folds during phonation (Awan et al., 2009; Heman-Ackah et al., 2003; Watts & Awan, 2011). CPP was significantly different between the control and VFN groups, with lower CPP values (corresponding to a more dysphonic voice) found in children with VFN. These results support prior research examining the reliability of CPP values in indicating the presence of dysphonia in a pediatric population (Esen Aydinli et al., 2019). Although CPP is now a recommended clinical tool for examining dysphonic voices for patients of all ages (Patel et al., 2018), ongoing work is needed to determine the appropriate normative values. CPP has been shown to vary as a function of age (Demirci et al., 2021; Infusino et al., 2015; Kent et al., 2021; Spazzapan et al., 2022), and Infusino and colleagues created a normative reference for CPP values in children (Infusino et al., 2015). However, it is important to note that this normative database used the Analysis of Dysphonia in Speech and Voice (ADSV) program to calculate CPP. In contrast, this study used the Praat program (Boersma & Weenick, 2019) to calculate CPP. CPP values can be reliably calculated using the ADSV program or Praat software; however, these individual programs use different algorithms to calculate CPP, and thus cannot be directly compared (Watts et al., 2017). Continued work is needed to understand the impact of development and VFN on CPP in children, independent of the program selected for calculation.

Limitations and Future Directions

The current study has several limitations that may have impacted the outcome. First, this study had a reduced age range, examining children between 6-12 years of age. This may have contributed to the lack of group differences in VOT averages. As VOT averages become adult-like around six years old (Kent, 1976; S. Whiteside & Marshall, 2001), it is possible that children in this study already had mature VOT productions that were not impacted by structural vocal changes. Second, additional information about the VFN participants was unknown, including the size of the VFN for each child or whether the child had further speech concerns that the parent did not note. It is possible that the majority of the participants had small VFN that did not impact vocal fold movement as much as larger VFN might have. Future work is needed to expand the age range to examine younger children and to include VFN characteristics that may impact phonation. Third, although formalized articulation testing was not completed in the current study, the analysis of VOT was completed manually. Thus, a trained analyst listened to every instance before the VOT calculation and would have noted any instances of inaccurate articulation in the speech sections of interest. It is possible that unforeseen differences in speech may have impacted the results, and future work would need to include formalized articulation testing to confirm these findings. Fourth, the retrospective nature of the design resulted in limited control of the recording environment, as data were collected at two locations. The analyses were structured to minimize these potential limitations, including evaluating only the voiced segments for CPP analysis and filtering the speech signals to help with vocalic onset identification, however, future work is needed to examine these potential confounds fully.

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REFERENCES

Abramson, A. S., & Whalen, D. H. (2017). Voice Onset Time (VOT) at 50: Theoretical and practical issues in measuring voicing distinctions. *Journal of Phonetics*, *63*, 75–86. https://doi.org/10.1016/J.WOCN.2017.05.002

Abur, D., Subaciute, A., Kapsner-Smith, M., Segina, R. K., Tracy, L. F., Noordzij, J. P., & Stepp, C. E. (2021). Impaired auditory discrimination and auditory-motor integration in hyperfunctional voice disorders. *Scientific Reports*, *11*, 13123. https://doi.org/10.1038/s41598-021-92250-8

Akif Kiliç, M., Okur, E., Yildirim, I., & Güzelsoy, S. (2004). The prevalence of vocal fold nodules in school age children. *International Journal of Pediatric Otorhinolaryngology*, *68*(4), 409–412.

Awan, S. N., Roy, N., & Dromey, C. (2009). Estimating dysphonia severity in continuous speech: Application of a multi-parameter spectralcepstral model estimating dysphonia severity in continuous speech. *Clinical Linguistics and Phonetics*, *23*(11), 825–841. https://doi.org/10.3109/02699200903242988

Barton, D., & Macken, M. A. (1980). An instrumental analysis of the voicing contrast in word-initial stops in the speech of four-year-old English-speaking children. *Language and Speech*, *23*(2), 159–169. https://doi.org/10.1177/002383098002300203

Bhattacharyya, N. (2015). The prevalence of pediatric voice and swallowing problems in the United States. *The Laryngoscope*, *125*(3), 746–750.

https://doi.org/10.1002/LARY.24931

Block, B. B., & Brodsky, L. (2007). Hoarseness in children: The role of laryngopharyngeal reflux. *International Journal of Pediatric Otorhinolaryngology*, *71*(9), 1361–1369. https://doi.org/10.1016/J.IJPORL.2006.10.029

Boersma, P., & Weenick, D. (2019). *Praat: doing phonetics by computer*.

Boseley, M. E., & Hartnick, C. J. (2006). Development of the human true vocal fold: Depth of cell layers and quantifying cell types within the lamina propria. *Annals of Otology, Rhinology and Laryngology*, *115*(10), 784–788. https://doi.org/10.1177/000348940611501012

Braden, M., van Leer, E., McConville, K., & Blakeslee, S. D. M. (2018). Patient, parent, and speech-language pathologists' perceptions of pediatric voice therapy through interviews. *American Journal of Speech-Language Pathology*, *27*(4), 1385–1404.

Brockmann-Bauser, M., Van Stan, J. H., Carvalho Sampaio, M., Bohlender, J. E., Hillman, R. E., & Mehta, D. D. (2021). Effects of vocal intensity and fundamental frequency on cepstral peak prominence in patients with voice disorders and vocally healthy controls. *Journal of Voice*, *35*(3), 411–417. https://doi.org/10.1016/J.JVOICE.2019.11.015

Carroll, L. M., Mudd, P., & Zur, K. B. (2013). Severity of voice handicap in children diagnosed with elevated lesions. *Otolaryngology - Head and Neck Surgery*, *149*(4), 628–632.

Connor, N. P., Cohen, S. B., Theis, S. M., Thibeault, S. L., Heatley, D. G., & Bless, D. M. (2008). Attitudes of children with dysphonia. *Journal of Voice*, *22*(2), 197–209.

Coyle, S. M., Weinrich, B. D., & Stemple, J. C. (2001). Shifts in Relative Prevalence of Laryngeal Pathology in a Treatment-Seeking Population. *Journal of Voice*, *15*(3), 424–440. https://doi.org/10.1016/S0892-1997(01)00043-1

De Bodt, M. S., Ketelslagers, K., Peeters, T., Wuyts, F. L., Mertens, F., Pattyn, J., Heylen, L., Peeters, A., Boudewyns, A., & Van de Heyning, P. (2007). Evolution of vocal fold nodules from childhood to adolescence. *Journal of Voice*, *21*(2), 151–156. https://doi.org/10.1016/J.JVOICE.2005.11.006

Demirci, A. N., Köse, A., Aydinli, F. E., İncebay, Ö., & Yilmaz, T. (2021). Investigating the cepstral acoustic characteristics of voice in healthy children. *International Journal of Pediatric Otorhinolaryngology*, *148*, 110815. https://doi.org/10.1016/J.IJPORL.2021.110815

Dobres, R., Lee, L., Stemple, J. C., Kummer, A. W., & Kretschmer, L. W. (1990). Description of Laryngeal Pathologies in Children Evaluated by Otolaryngologists. *Journal of Speech and Hearing Disorders*, *55*(3), 526–532. https://doi.org/10.1044/JSHD.5503.526

Döllinger, M., Dubrovskiy, D., & Patel, R. R. (2012). Spatiotemporal analysis of vocal fold vibrations between children and adults. *The Laryngoscope*, *122*(11), 2511–2518. https://doi.org/10.1002/lary.23568

Eguchi, S., & Hirsh, I. J. (1969). Development of speech sounds in children. *Acta Oto-Laryngologica, Supplement*, *257*, 1–51.

Esen Aydinli, F., Özcebe, E., & İncebay, Ö. (2019). Use of cepstral analysis for differentiating dysphonic from normal voices in children. *International Journal of*

Pediatric Otorhinolaryngology, *116*, 107–113. https://doi.org/10.1016/J.IJPORL.2018.10.029

Galindo, G. E., Peterson, S. D., Erath, B. D., Castro, C., Hillman, R. E., & Zañartu, M. (2017). Modeling the pathophysiology of phonotraumatic vocal hyperfunction with a triangular glottal model of the vocal folds. *Journal of Speech, Language, and Hearing Research*, *60*(9), 2452–2471. https://doi.org/10.1044/2017_JSLHR-S-16-0412

Hammond, T. H., Gray, S., Butler, J., Zhou, R., & Hammond, E. (1998). A study of age and gender related elastin distribution changes in human vocal folds. *Otolaryngology - Head and Neck Surgery*, *119*(4), 314–322. https://doi.org/10.1016/s0194-5998(97)80153-2

Hammond, T. H., Steven Gray, O. D., & Butler, J. E. (2000). Age- and gender-related collagen distribution in human vocal folds. *Annals of Otology, Rhinology and Laryngology*, *109*, 913–920.

Hartnick, C. J., Rehbar, R., & Prasad, V. (2005). Development and maturation of the pediatric human vocal fold lamina propria. *The Laryngoscope*, *115*(1), 4–15. https://doi.org/10.1097/01.mlg.0000150685.54893.e9

Heller Murray, E., & Chao, A. (2021). The relationships between pediatric dysphonia, vocal variability, and vocal-articulatory coordination. *Journal of Voice*, *Available*.

Heller Murray, E., Chao, A., & Colletti, L. (2022). A practical guide to calculating cepstral peak prominence in Praat. *Journal of Voice*. https://doi.org/10.31219/osf.io/yvp4s

Heller Murray, E., Hands, G. L., Calabrese, C. R., & Stepp, C. E. (2016). Effects of adventitious acute vocal trauma: relative fundamental frequency and listener perception. *Journal of Voice*, *30*(2), 177–185. https://doi.org/10.1016/J.JVOICE.2015.04.005

Heller Murray, E., Hseu, A. F., Nuss, R. C., Harvey Woodnorth, G., & Stepp, C. E. (2019). Vocal pitch discrimination in children with and without vocal fold nodules. *Applied Sciences*, *9*(15), 3042. https://doi.org/10.3390/app9153042

Heller Murray, E., Lien, Y. A., Van Stan, J. H., Mehta, D. D., Hillman, R. E., Pieter Noordzij, J., & Steppa, C. E. (2017). Relative fundamental frequency distinguishes between phonotraumatic and non-phonotraumatic vocal hyperfunction. *Journal of Speech, Language, and Hearing Research*, *60*(6), 1507–1515. https://doi.org/10.1044/2016_JSLHR-S-16-0262

Heller Murray, E., Segina, R. K., Woodnorth, G. H., & Stepp, C. E. (2020). Relative fundamental frequency in children with and without vocal fold nodules. *Journal of Speech, Language, and Hearing Research*, *63*(2), 361–371. https://doi.org/10.1044/2019_JSLHR-19-00058

Heman-Ackah, Y. D., Heuer, R. J., Michael, D. D., Ostrowski, R., Horman, M., Baroody, M. M., Hillenbrand, J., & Sataloff, R. T. (2003). Cepstral peak prominence: A more reliable measure of dysphonia. *Annals of Otology, Rhinology and Laryngology*, *112*(4), 324–333. https://doi.org/10.1177/000348940311200406

Heman-Ackah, Y. D., Michael, D. D., & Goding, G. S. (2002). The relationship between cepstral peak prominence and selected parameters of dysphonia. *Journal of Voice*, *16*(1), 20–27. https://doi.org/10.1016/S0892-1997(02)00067-X

Hillenbrand, J., Cleveland, R. A., & Erickson, R. L. (1994). Acoustic correlates of breathy vocal quality. *Journal of Speech and Hearing Research*, *37*(4), 769–778. https://doi.org/10.1044/JSHR.3704.769

Hillenbrand, James, & Houde, R. A. (1996). Acoustic correlates of breathy vocal quality: Dysphonic voices and continuous speech. *Journal of Speech, Language, and Hearing Research, 39*(2), 311–321. https://doi.org/10.1044/JSHR.3902.311

Hillman, R. E., Holmberg, E. B., Perkell, J. S., Walsh, M., & Vaughan, C. (1989). Objective assessment of vocal hyperfunction. *Journal of Speech, Language, and Hearing Research*, *32*(2), 373–392. https://doi.org/10.1044/JSHR.3202.373

Hillman, R. E., Stepp, C. E., Van Stan, J. H., Zañartu, M., & Mehta, D. D. (2020). An updated theoretical framework for vocal hyperfunction. *American Journal of Speech-Language Pathology*, 1–7. https://doi.org/10.1044/2020_AJSLP-20-00104

Hirano, M., Kurita, S., & Nakashima, T. (1983). Growth, development and aging of human vocal fold. In D. M. Bless & J. H. Abbs (Eds.), *Vocal Fold Physiology: Contemporay Research and Clinical Issues* (pp. 22–43). College-Hill Press.

Hitchcock, E. R., & Koenig, L. L. (2013). The effects of data reduction in determining the schedule of voicing acquisition in young children. *Journal of Speech, Language, and Hearing Research*, *56*(2), 441–457. https://doi.org/10.1044/1092-4388(2012/11-0175)

Infusino, S. A., Diercks, G. R., Rogers, D. J., Garcia, J., Ojha, S., Maurer, R., Bunting, G., & Hartnick, C. J. (2015). Establishment of a normative cepstral pediatric acoustic database. *JAMA Otolaryngology - Head and Neck Surgery*, *141*(4), 358–363. https://doi.org/10.1001/jamaoto.2014.3545

Ishii, K., Yamashita, K., Akita, M., & Hirose, H. (2000). Age-related development of the arrangement of connective tissue fibers in the lamina propria of the human vocal fold. *Annals of Otology, Rhinology and Laryngology*, *109*(11), 1055–1064. https://doi.org/10.1177/000348940010901112

Kapsner-Smith, M. R., Díaz-Cádiz, M. E., Vojtech, J. M., Buckley, D. P., Mehta, D. D., Hillman, R. E., Tracy, L. F., Pieter Noordzij, J., Eadie, T. L., & Stepp, C. E. (2022). Clinical Cutoff Scores for Acoustic Indices of Vocal Hyperfunction That Combine Relative Fundamental Frequency and Cepstral Peak Prominence. *Journal of Speech, Language, and Hearing Research*, *65*(4), 1349–1369. https://doi.org/10.1044/2021_JSLHR-21-00466

Kempster, G. B., Gerratt, B. R., Verdolini Abbott, K., Barkmeier-Kraemer, J., & Hillman, R. E. (2009). Consensus auditory-perceptual evaluation of voice: Development of a standardized clinical protocol. *American Journal of Speech-Language Pathology*, *18*(2), 124–132. https://doi.org/10.1044/1058-0360(2008/08-0017)

Kent, R. D. (1976). Anatomical and neuromuscular maturation of the speech mechanism: evidence from acoustic studies. *Journal of Speech and Hearing Research*, *19*(3), 421–445. https://doi.org/10.1044/JSHR.1903.421

Kent, R. D., Eichhorn, J. T., & Vorperian, H. K. (2021). Acoustic parameters of voice in typically developing children ages 4–19 years. *International Journal of Pediatric*

Otorhinolaryngology, *142*, 110614.

Kessinger, R. H., & Blumstein, S. E. (1998). Effects of speaking rate on voice-onset time and vowel production: Some implications for perception studies. *Journal of Phonetics*, *26*(2), 117–128. https://doi.org/10.1006/JPHO.1997.0069

Kewley-Port, D., & Preston, M. S. (1974). Early apical stop production: A voice onset time analysis. *Journal of Phonetics*, *2*(3), 195–210. https://doi.org/10.1016/s0095-4470(19)31270-7

Koenig, L. L. (2000). Laryngeal factors in voiceless consonant production in men, women, and 5-year-olds. *Journal of Speech, Language, and Hearing Research*, *43*(5), 1211–1228. https://doi.org/10.1044/jslhr.4305.1211

Koenig, L. L. (2001). Distributional characteristics of VOT in children's voiceless aspirated stops and interpretation of developmental trends. *Journal of Speech, Language, and Hearing Research*, *44*(5), 1058–1068. https://doi.org/10.1044/1092-4388(2001/084)

Koo, T. K., & Li, M. Y. (2016). A Guideline of Selecting and Reporting Intraclass Correlation Coefficients for Reliability Research. *Journal of Chiropractic Medicine*, *15*(2), 155. https://doi.org/10.1016/J.JCM.2016.02.012

Lien, Y.-A. S., & Stepp, C. E. (2014). Comparison of voice relative fundamental frequency estimates derived from an accelerometer signal and low-pass filtered and unprocessed microphone signals. *The Journal of the Acoustical Society of America*, *135*(5), 2977–2985. https://doi.org/10.1121/1.4870488

Lisker, L., & Abramson, A. S. (1964). A cross-language study of voicing in initial stops:

acoustical measurements. *Word*, *20*(3), 384–422. https://doi.org/10.1080/00437956.1964.11659830

Lisker, L., & Abramson, A. S. (1967). Some effects of context on voice onset time in english stops. *Language and Speech*, *10*(1), 1–28. https://doi.org/10.1177/002383096701000101

Lohscheller, J., & Eysholdt, U. (2008). Phonovibrogram visualization of entire vocal fold dynamics. *The Laryngoscope*, *118*(4), 753–758. https://doi.org/10.1097/MLG.0B013E318161F9E1

Macken, M. A., & Barton, D. (1980). The acquisition of the voicing contrast in English: A study of voice onset time in word-initial stop consonants. *Journal of Child Language*, *7*(1), 41–74.

Martins, R. H. G., Hidalgo Ribeiro, C. B., Fernandes De Mello, B. M. Z., Branco, A., & Tavares, E. L. M. (2012). Dysphonia in children. *Journal of Voice*, *26*(5), 674.e17-674.e20. https://doi.org/10.1016/j.jvoice.2012.03.004

McKenna, V. S., Hylkema, J. A., Tardif, M. C., & Stepp, C. E. (2020). Voice onset time in individuals with hyperfunctional voice disorders: evidence for disordered vocal motor control. *Journal of Speech, Language, and Hearing Research*, *63*(2), 405–420. https://doi.org/10.1044/2019_JSLHR-19-00135

Murton, O., Hillman, R., & Mehta, D. (2020). Cepstral peak prominence values for clinical voice evaluation. *American Journal of Speech-Language Pathology*, *29*(3), 1596–1607. https://doi.org/10.1044/2020_AJSLP-20-00001

Ongkasuwan, J., & Friedman, E. M. (2013). Is voice therapy effective in the management of vocal fold nodules in children? *Laryngoscope*, *123*(12), 2930–2931. https://doi.org/10.1002/lary.23830

Özçelik Korkmaz, M., & Tüzüner, A. (2020). The role of nutritional and dietary habits in etiology in pediatric vocal old Nodules. *Journal of Voice*. https://doi.org/10.1016/j.jvoice.2020.09.007

Patel, R. R., Awan, S. N., Barkmeier-Kraemer, J., Courey, M., Deliyski, D., Eadie, T., Paul, D., Švec, J. G., & Hillman, R. (2018). Recommended protocols for instrumental assessment of voice: American speech-language-hearing association expert panel to develop a protocol for instrumental assessment of vocal function. *American Journal of Speech-Language Pathology*, *27*(3), 887–905. https://doi.org/10.1044/2018_AJSLP-17-0009

Patel, R. R., Dixon, A., Richmond, A. M., & Donohue, K. D. (2012). Pediatric high speed digital imaging of vocal fold vibration: A normative pilot study of glottal closure and phase closure characteristics. *International Journal of Pediatric Otorhinolaryngology*, *76*(7), 954–959. https://doi.org/10.1016/j.ijporl.2012.03.004

Patel, R. R., Donohue, K. D., Unnikrishnan, H., & Kryscio, R. J. (2015). Kinematic measurements of the vocal-fold displacement waveform in typical children and adult populations: Quantification of high-speed endoscopic videos. *Journal of Speech, Language, and Hearing Research*, *58*(2), 227–240. https://doi.org/10.1044/2015_JSLHR-S-13-0056

Patel, R. R., Dubrovskiy, D., & Döllinger, M. (2014a). Characterizing vibratory kinematics in children and adults with high-speed digital imaging. *Journal of*

Speech, Language, and Hearing Research, *57*(2), 674–686. https://doi.org/10.1044/2014_JSLHR-S-12-0278

Patel, R. R., Dubrovskiy, D., & Döllinger, M. (2014b). Measurement of glottal cycle characteristics between children and adults: Physiological variations. *Journal of Voice*, *28*(4), 476–486. https://doi.org/10.1016/j.jvoice.2013.12.010

Patel, R. R., Unnikrishnan, H., & Donohue, K. D. (2016). Effects of vocal fold nodules on glottal cycle measurements derived from high-speed videoendoscopy in children. *PLOS ONE*, *11*(4), e0154586. https://doi.org/10.1371/journal.pone.0154586

Rogers, D. J., Setlur, J., Raol, N., Maurer, R., & Hartnick, C. J. (2014). Evaluation of true vocal fold growth as a function of age. *Otolaryngology - Head and Neck Surgery (United States)*, *151*(4), 681–686. https://doi.org/10.1177/0194599814547489

Roy, N., Fetrow, R. A., Merrill, R. M., & Dromey, C. (2016). Exploring the clinical utility of relative fundamental frequency as an objective measure of vocal hyperfunction. *Journal of Speech, Language, and Hearing Research*, *59*(5), 1002–1017. https://doi.org/10.1044/2016_JSLHR-S-15-0354

Sampaio, M., Masson, M. L. V., Soares, M. F. de P., Bohlender, J. E., & Brockmann-Bauser, M. (2020). Effects of fundamental frequency, vocal intensity, sample duration, and vowel context in cepstral and spectral measures of dysphonic voices. *Journal of Speech, Language, and Hearing Research*, *63*(5), 1326–1339. https://doi.org/10.1044/2020_JSLHR-19-00049

Sapienza, C. M., & Stathopoulos, E. T. (1994). Respiratory and laryngeal measures of children and women with bilateral vocal fold nodules. *Journal of Speech and*

Hearing Research, *37*(6), 1229–1243. https://doi.org/10.1044/JSHR.3706.1229

SAS Institute. (2019). *JMP* (p. Version 15.1.0).

Sato, K., Hirano, M., & Nakashima, T. (2001). Fine structure of the human newborn and infant vocal fold mucosae. *Annals of Otology, Rhinology and Laryngology*, *110*(5 I), 417–424. https://doi.org/10.1177/000348940111000505

Sato, K., Sakamoto, K., & Nakashima, T. (2006). Expression and distribution of CD44 and hyaluronic acid in human vocal fold mucosa. *Annals of Otology, Rhinology and Laryngology*, *115*(10), 741–748. https://doi.org/10.1177/000348940611501005

Sauder, C., Bretl, M., & Eadie, T. (2017). Predicting voice disorder status from smoothed measures of cepstral peak prominence using Praat and Analysis of Dysphonia in Speech and Voice (ADSV). *Journal of Voice*, *31*(5), 557–566. https://doi.org/10.1016/J.JVOICE.2017.01.006

Schweinfurth, J. M., & Thibeault, S. L. (2008). Does hyaluronic acid distribution in the larynx relate to the newborn's capacity for crying? *The Laryngoscope*, *118*(9), 1692–1699. https://doi.org/10.1097/MLG.0b013e3181782754

Shah, R. K., Woodnorth, G. H., Glynn, A., & Nuss, R. C. (2005). Pediatric vocal nodules: Correlation with perceptual voice analysis. *International Journal of Pediatric Otorhinolaryngology*, *69*(7), 903–909. https://doi.org/10.1016/j.ijporl.2005.01.029

Shearer, W. M. (1972). Diagnosis and treatment of voice disorders in school children. *Journal of Speech and Hearing Disorders*, *37*(2), 215–221.

Simpson, C. B., & Rosen, C. A. (2008). Benign diseases of the vocal fold lamina. In *Operative techniques in laryngology* (pp. 23–27). Springer.

Sodersten, M., & Lindestad, P. A. (1990). Glottal closure and perceived breathiness during phonation in normally speaking subjects. *Journal of Speech and Hearing Research*, *33*(3), 601–611. https://doi.org/10.1044/JSHR.3303.601

Spazzapan, E. A., Marino, V. C. de C., & Fabbron, E. M. G. (2022). Smoothed cepstral peak analysis of Brazilian children and adolescents speakers. *Journal of Voice*. https://doi.org/10.1016/J.JVOICE.2022.02.002

Stepp, C. E., Hillman, R. E., & Heaton, J. T. (2010). The impact of vocal hyperfunction on relative fundamental frequency during voicing offset and onset. *Journal of Speech, Language, and Hearing Research*, *53*(5), 1220–1226. https://doi.org/10.1044/1092-4388(2010/09-0234)

Stepp, C. E., Lester-Smith, R. A., Abur, D., Daliri, A., Pieter Noordzij, J., & Lupiani, A. A. (2017). Evidence for auditory-motor impairment in individuals with hyperfunctional voice disorders. *Journal of Speech, Language, and Hearing Research*, *60*(6), 1545–1550. https://doi.org/10.1044/2017_JSLHR-S-16-0282

Stepp, C. E., Merchant, G. R., Heaton, J. T., & Hillman, R. E. (2011). Effects of Voice Therapy on Relative Fundamental Frequency During Voicing Offset and Onset in Patients With Vocal Hyperfunction. *Journal of Speech, Language, and Hearing Research*, *54*(5), 1260–1266. https://doi.org/10.1044/1092-4388(2011/10-0274)

Tavares, E. L. M., Brasolotto, A., Santana, M. F., Padovan, C. A., & Martins, R. H. G. (2011). Epidemiological study of dysphonia in 4-12 year-old children. *Brazilian Journal of Otorhinolaryngology*, *77*(6), 736–746. https://doi.org/10.1590/s1808-86942011000600010

Van Stan, J. H., Roy, N., Awan, S., Stemple, J., & Hillmana, R. E. (2015). A taxonomy of voice therapy. *American Journal of Speech-Language Pathology*, *24*(2), 101–125.

Verdolini Abbott, K. (2013). Some guiding principles in emerging models of voice therapy for children. *Seminars in Speech and Language*, *34*(2), 80–93. https://doi.org/10.1055/S-0033-1342979/ID/JR00507-52

Verduyckt, I., Remacle, M., Jamart, J., Benderitter, C., & Morsomme, D. (2011). Voice-related complaints in the pediatric population. *Journal of Voice*, *25*(3), 373–380.

Volaitis, L. E., & Miller, J. L. (1992). Phonetic prototypes: influence of place of articulation and speaking rate on the internal structure of voicing categories. *The Journal of the Acoustical Society of America*, *92*(2 Pt 1), 723–735. https://doi.org/10.1121/1.403997

Vorperian, H. K., & Kent, R. D. (2007). Vowel acoustic space development in children: A synthesis of acoustic and anatomic data. *Journal of Speech, Language, and Hearing Research*, *50*(6), 1510–1545. https://doi.org/10.1044/1092-4388(2007/104)

Vorperian, H. K., Wang, S., Chung, M. K., Schimek, E. M., Durtschi, R. B., Kent, R. D., Ziegert, A. J., & Gentry, L. R. (2009). Anatomic development of the oral and pharyngeal portions of the vocal tract: An imaging study. *The Journal of the Acoustical Society of America*, *125*(3), 1666–1678. https://doi.org/10.1121/1.3075589

Watts, C. R., & Awan, S. N. (2011). Use of spectral/cepstral analyses for differentiating normal from hypofunctional voices in sustained vowel and continuous speech contexts. *Journal of Speech, Language, and Hearing Research*, *54*(6), 1525–1537.

https://doi.org/10.1044/1092-4388(2011/10-0209)

Watts, C. R., Awan, S. N., & Maryn, Y. (2017). A comparison of cepstral peak prominence measures from two acoustic analysis programs. *Journal of Voice*, *31*(3), 387.e1-e10. https://doi.org/10.1016/j.jvoice.2016.09.012

Whiteside, S., Dobbin, R., & Henry, L. (2003). Patterns of variability in voice onset time: A developmental study of motor speech skills in humans. *Neuroscience Letters*, *347*(1), 29–32. https://doi.org/10.1016/S0304-3940(03)00598-6

Whiteside, S., & Marshall, J. (2001). Developmental trends in voice onset time: Some evidence for sex differences. *Phonetica*, *58*(3), 196–210. https://doi.org/10.1159/000056199

Whiteside, S. P., Henry, L., & Dobbin, R. (2004). Sex differences in voice onset time: A developmental study of phonetic context effects in British English. *The Journal of the Acoustical Society of America*, *116*(2), 1179–1183. https://doi.org/10.1121/1.1768256

Yamauchi, A., Yokonishi, H., Imagawa, H., Sakakibara, K. I., Nito, T., Tayama, N., & Yamasoba, T. (2016). Quantification of vocal fold vibration in various laryngeal disorders using high-speed digital imaging. *Journal of Voice*, *30*(2), 205–214. https://doi.org/10.1016/J.JVOICE.2015.04.016

Yu, V. Y., De Nil, L. F., & Pang, E. W. (2015). Effects of age, sex and syllable number on voice onset time: Evidence from children’s voiceless aspirated stops. *Language and Speech*, *58*(2), 152–167. https://doi.org/10.1177/0023830914522994

Yu, V. Y., Kadis, D. S., Oh, A., Goshulak, D., Namasivayam, A., Pukonen, M., Kroll, R., De Nil, L. F., & Pang, E. W. (2014). Changes in voice onset time and motor speech skills in children following motor speech therapy: Evidence from /pa/ productions. *Clinical Linguistics and Phonetics*, *28*(6), 396–412. https://doi.org/10.3109/02699206.2013.874040

Zlatin, M. A., & Koenigsknecht, R. A. (1976). Development of the voicing contrast: A comparison of voice onset time in stop perception and production. *Journal of Speech and Hearing Research*, *19*(1), 93–111. https://doi.org/10.1044/jshr.1901.93