Effects of Age on Voice Onset Time and Variability in Children with Repaired Cleft Palate

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Keywords

Voice onset time · Variability · Cleft palate · Age · Adolescents

Abstract

Objective: To examine the effect of age on voice onset time (VOT) and VOT variability in children with repaired cleft palate. **Methods:** Twenty-two children with repaired cleft palate were allocated into two age groups: younger children (YC: $n = 13$) and older children (OC: $n = 9$). VOT measurements from monosyllabic words (/pa/, /ta/, and /ka/) and intraspeaker VOT variability estimated by coefficients of variation (CoV) of two age groups were compared. **Results:** Age was found to have a statistically significant effect on VOT and VOT variability. Specifically, OC had significantly longer VOT ($F(1,66) = 4.196, p < 0.05$) and less VOT variability ($F(1,66) = 6.007, p < 0.05$) for English voiceless stops than YC. No statistically significant main effect for speech sample or age by speech sample interaction was observed. **Conclusions:** Our data supplement the existing literature by adding VOT and VOT variability information for older children/adolescents with repaired cleft palate. Findings from the study suggest VOT patterns acquired at younger age appear to be further exaggerated and stabilized during the adolescent period among children with repaired cleft palate. A future study is

necessary to determine different sources of VOT variability in children with a history of cleft palate, which may have clinical therapeutic implications.

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Introduction

Speech is an output of the complex and coordinated interplay among the speech subsystems. The intertwined relationships among the speech subsystems can be partly exemplified by the physiologic effects of supraglottal pressure on vocal fold behaviors [1, 2]. Specifically, the buildup of intraoral pressure during a stop closure period is known to inhibit vocal fold vibration [1]. A sudden release of the oral constriction, however, generates a transglottal pressure difference, facilitating vocal fold oscillation. Inadequate valving of the velopharyngeal (VP) port, commonly seen in individuals with a history of cleft palate, alters the aerodynamic environment, which may subsequently affect laryngeal valving patterns. Previous studies have reported somewhat lower intraoral pressure in individuals with cleft palate compared to those without cleft palate [3, 4], indicating the possible impact of incomplete VP closure on the speaker's ability to generate intraoral pressure required during speech production. It is im-

portant, however, to note that the majority of speakers with cleft palate in Dalston et al. [3] were able to maintain at least 3 cmH₂O of intraoral pressure. Data from the Mayo et al. study [4] also showed statistically nonsignificant differences between speakers with and without adequate VP closure in the level of intraoral pressure. That is, some speakers with inadequate VP closure may have the ability to maintain stable intraoral pressure while offsetting the compromised valving mechanism.

One acoustic parameter reflecting the temporal interaction between the laryngeal and the supralaryngeal system is voice onset time (VOT), which is defined as the time interval between the release of the oral closure and the following voicing [5]. Since Fletcher [6] posed the question specific to the potential interactions between the presence of palatal clefts and its potential impact on VOT, only a few studies have explored VOT variations among individuals with a history of cleft palate and the reported results are conflicting. Unless altered by compensatory maneuvers, it seems reasonable to hypothesize that inadequate VP closure accompanied by somewhat reduced intraoral pressure may facilitate vocal fold vibration, possibly resulting in short VOTs. A recent study [7] showed that Mandarin-speaking children with repaired cleft palate and hypernasality were found to have shorter VOTs than control peers with normal resonance. Those children with hypernasality secondary to cleft palate indeed had negative VOTs for an unaspirated voiceless stop, resulting in a voicing change of the targeted consonant production, which appears to be in agreement with the hypothesized direction of change in VOTs. In contrast, Forner [8] reported that 5- and 6-year-old, English-speaking children with cleft palate had longer stop gap periods and VOTs compared to those without cleft palate. Similarly, Persian-speaking children with cleft palate were found to have longer stop gap periods as well as VOTs than those without cleft palate [9]. Overall lengthened temporal durations observed in these studies were attributed to a compensatory maneuver (i.e., increased respiratory effort) employed by children with cleft palate [8, 9].

Taken together, temporal coordination patterns between the laryngeal and the supralaryngeal systems remain undetermined among individuals with a history of cleft palate due to the complexities of interplay between the speaker's underlying anatomic or physiologic constraints and behavioral adjustments. VOT plays an important role in making phonemic and phonetic distinctions among different stops in a given language; for example, stop cognate pairs of English differ only in voicing.

A speaker's inability to produce voiceless stops with long lag VOTs distinctly from voiced stops will likely have a negative impact on his/her communication skills. The other end of the VOT continuum, longer VOTs for voiceless stops in children with repaired cleft palate than typical peers, has been explained in association with an increased respiratory drive [8, 9]. Perceptual consequences of this "overshoot" behavior is unknown. Nevertheless, it is reasonable to speculate that adopting such a behavior may be somewhat challenged in connected speech, especially when articulatory gestures are imposed by stringent timing constraints. Maintaining an overshoot behavior may also be achieved by having another speech subsystem overworked: e.g., increased laryngeal tension reported in children with a history of cleft palate [10, 11].

One of many speaker-dependent factors known to affect VOTs is the speaker's age [12–17]. Typical children achieve adult-like VOTs by approximately 11 years of age and continue to refine their motor skills during adolescence [18–20]. Age-related VOT changes described in previous research, however, have been somewhat inconsistent. For example, Zlatin and Koenigsnecht [12] reported longer VOTs in adults compared to 2-year-old or 6-year-old children, whereas Barton and Macken [13] showed an opposite pattern with 4-year-old children having longer VOTs than the reported adult data from Lisker and Abramson [5]. Supporting the pattern observed by Barton and Macken [13] is a recent cross-sectional VOT study [20], which compared mean VOTs of voiceless stops across eight different age groups ranging from 4 years to young adults. The results from that study showed a significant VOT decrease as a function of age. Unlike the inconclusive relationship between the VOT direction and age that has shown varied results, a robust relationship has been found between VOT variability and age in voiceless stop production; overall VOT variability decreases from childhood to adulthood [2, 12, 13, 20].

It is unknown whether or not and to what extent these developmental VOT and VOT variability patterns would hold true in children with repaired cleft palate, largely due to limited data. Previous case control studies [7–9] have focused on identifying differences between the groups with and without cleft palate in VOT or other temporal measures of stop productions concerning young children with the age range between 4 and 13 years. To the best of our knowledge, no studies have described VOT and VOT variability patterns in older children/adolescents with repaired cleft palate. Given the developmental trajectory of VOT expected during the adolescent period (i.e., further refinement and stability in VOT productions), it is im-

portant to supplement the literature by adding VOT descriptions of older children/adolescents with repaired cleft palate. Such data may provide some clinical insight into the nature of different maneuvers adopted by individual speakers to offset anatomic or physiologic constraints while leveraging developmental maturation processes of the speech subsystems. Therefore, the present study examined the effects of age on VOT and VOT variability patterns in children with repaired cleft palate by making comparisons between two age groups: younger (6–11 years) and older (12–18 years) children. It was hypothesized that the two age groups would differ from each other in VOT and VOT variability patterns. Given that no particular trend has been agreed upon in the literature regarding the direction of VOT changes across age, the present study aimed at providing exploratory analysis of VOT differences between two age groups. With regard to VOT variability, it was predicted that younger children would have greater VOT variability than older children, reflecting the same developmental trajectory of typical children as reported in previous research [2, 12, 13, 20].

Methods

Participants

This study was approved by the university institutional review board and informed consents were reviewed and signed by all participants. Data were collected retrospectively from a large database of children from southern New Mexico and western Texas who attended the university-based cleft palate clinic. It is worthwhile to mention that a majority of the patients seen in the cleft palate clinic were from rural areas and had been treated by different surgeons other than the team surgeon, with significantly delayed introduction to interdisciplinary team care. Thus, specific details of the surgical procedures were not available. Inclusion/exclusion criteria were as follows; children spoke American English as their first language and had no known syndromes, symptomatic fistulae, audiologic concerns, or compensatory misarticulations. Given that durational measures, including VOTs, may be influenced by severity of articulation disorders and speech intelligibility [8, 21, 22], it was deemed appropriate to exclude children with compensatory misarticulations from the present study.

Twenty-two children (12 females and 10 males) who had repaired cleft palate were included in this study. Eleven children had bilateral cleft lip and palate (BCLP), 6 had unilateral cleft lip and palate (UCLP), and 5 had isolated cleft palate (CP). The age of the participants ranged between 6 and 18 years with a mean of 11.2 years (SD: 4.3). While the type of primary palatoplasty was unknown, all participants received surgical repair between the ages of 8 and 18 months with no secondary surgery, except for one participant who received palatal repair at a later age. Only one participant was receiving speech-language therapy at the time of data collection. As part of the university cleft palate clinic protocol, the

Table 1. Summary of participants' sex, age, cleft type, and perceptual speech ratings

	YC (<i>n</i> = 13)	OC (<i>n</i> = 9)
Sex, <i>n</i>		
Boys	5	5
Girls	8	4
Age, years		
6	2	
7	2	
8	5	
9	3	
10	1	
12		1
13		1
15		1
16		1
17		3
18		2
Cleft		
BCLP	6	5
UCLP	3	3
CP	4	1
Hypernasality		
Normal	6	2
Mild	6	5
Moderate	1 ^a	2
Nasal air emission	4	4

^a Mixed resonance (hypernasality and hyponasality) was noted.

perceptual assessment was performed by an experienced speech-language pathologist who was not part of the research team. Hypernasality ratings were determined based on a variety of speech tasks (sustained vowels, repetitions of consonant-vowel [CV] sequences, sentences, and spontaneous speech) using a 4-point rating scale (0: none, 1: mild, 2: moderate, and 3: severe). Binary judgments of presence or absence were used for hyponasality ratings. Of 22 participants, 8 participants were rated to have normal resonance, 11 participants were rated to have mild hypernasality, and 3 participants were rated to have moderate hypernasality. One of the participants with moderate hypernasality was judged to have mixed resonance with the presence of hyponasality as well. One participant with normal resonance had phoneme-specific nasal emission on sibilants, which did not affect the stop consonant production and thus was included in the subsequent analyses. Eight of 14 participants with hypernasality also exhibited audible nasal air emission with positive mirror test results. Given that children's VOT patterns for voiceless stops approximate adult-like patterns at around 11 years [18, 20], participants were divided into two age groups: younger children below 12 years (YC, mean: 7.9 years, SD: 1.19) and older children at or above 12 years (OC, mean: 15.9 years, SD 2.15). Table 1 provides summary information on the participant's age, sex, cleft type, and speech status for the two age groups separately.

Fig. 1. Production of /pa/ visualized on the waveform and spectrographic analyses. VOT is the time interval between the two dashed lines.

Data Collection and Analyses

Speech stimuli consisted of repetitions of three monosyllable words: /pa/, /ta/, and /ka/. Five repetitions of each stimulus were analyzed and included for subsequent analyses. All speech samples were recorded using the Nasometer II (Model 6450; KayPENTAX™, Montvale, NJ, USA). The Nasometer headgear fit comfortably, but tightly secured against the participant's face between the nose and the upper lip. All acoustic signals recorded by the Nasometer microphone set were subject to a filtering process through the Nasometer band-pass filter, which has its center frequency at 500 Hz with a 300 Hz bandwidth. Participants were instructed to produce the speech sample at their comfortable rate and loudness level.

Defined as the interval between the stop release and the onset of voicing, VOT measurements were taken from the acoustic signal recorded through the oral-channel microphone of the Nasometer using PRAAT speech analysis software [23]. The use of oscillographic waveform and spectrographic information guided VOT measurements in milliseconds (ms), as illustrated in Figure 1 [24]. When a double burst was present, VOT measurements were taken from the beginning of the first burst [25]. The onset of voicing was identified as the time point at which periodic striations representing glottal pulses begin. In addition, intraspeaker VOT variability was estimated by means of coefficients of variation (CoV = standard deviation divided by mean in percent) as a unit-free, relative VOT dispersion measure.

Reliability

Interraters reliability was assessed based on two datasets independently measured by two raters on a randomly selected set comprising of 12% of VOT measurements. With the intraclass correlation coefficient (ICC) of 0.98, the mean difference between the two raters was 2 ms (SD: 2), and 85% of measurements were within 4 ms.

Table 2. VOT and VOT variability represented by CoV for YC and OC across three different speech samples

Speech sample	VOT, ms		CoV, %	
	YC, <i>n</i> = 13 (6–11 years)	OC, <i>n</i> = 9 (12–18 years)	YC, <i>n</i> = 13 (6–11 years)	OC, <i>n</i> = 9 (12–18 years)
/pa/	62 (13)	67 (21)	27 (16)	16 (7)
/ta/	71 (18)	80 (23)	22 (9)	19 (9)
/ka/	68 (20)	84 (24)	26 (10)	21 (15)
Mean	67 (17)	77 (23)	25 (11)	18 (10)

Values are expressed as means with standard deviations in parentheses. VOT, voice onset time; CoV, coefficient of variation; YC, younger children; OC, older children.

Statistical Treatment

Two separate two-way linear mixed model analyses were employed to test the effects of age (YC vs. OC) and speech sample (/pa/, /ta/, and /ka/) on VOT and VOT variability. For each analysis, age served as a between-subjects fixed factor, speech sample served as a within-subjects fixed factor, and participant served as a random factor. All statistical tests were performed using SPSS Statistic (Version 22.0, Armonk, NY, USA) at a significance level of $\alpha < 0.05$.

Results

Descriptive VOT and VOT variability data are presented in Table 2. Age was found to have a statistically significant main effect ($F(1,66) = 4.196, p < 0.05$) on VOTs, in which OC (77 ms) had longer VOTs than YC (67 ms). No statistically significant main effect for speech sample or interaction between age and speech sample was observed.

Similar patterns were observed, in which age had a statistically significant main effect ($F(1,66) = 6.007, p < 0.05$) on VOT variability represented by CoV (%), in which OC (18%) demonstrated less VOT variability than YC (26%). Neither the main effect for speech sample nor the interaction term between age and speech sample were statistically significant.

Discussion

Previous developmental VOT studies have shown that typical children acquire adult-like VOT patterns for voiceless stop consonants in early adolescence and con-

tinue to undergo further maturation processes during the adolescent period [18, 20]. Relatively little is understood regarding the VOT patterns by age among children with repaired cleft palate, partly because previous studies have largely been confined to young children between the age of 4 and 13 years [7–9]. The present study examined the effects of age on VOT and VOT variability for the production of three English voiceless stop consonants in children with repaired cleft palate. Participating children were clustered into two age groups: YC (6–11 years) versus OC (12–18 years). Results showed statistically significant differences between the two age groups in VOT and VOT variability; specifically, our data showed that OC had longer VOT with less VOT variability than YC.

No *a priori* directional pattern was hypothesized regarding VOT differences between two age groups with repaired cleft palate, as the existing literature on VOT changes across age has shown varied results. The result of longer VOTs observed in OC compared to YC seemingly corroborates the finding of Zlatin and Koenigsnecht [12], reflecting that further refinement of the voicing contrast might have taken place toward the direction of lengthening the VOTs for voiceless stops during the adolescent period among children with repaired cleft palate. If this indeed is a developmental process, some children with repaired cleft palate who presented with no adequate voicing contrast at a young age (e.g., children with hypernasality in Jiang et al. [7]) may have a chance to gain improved production of voiceless stops during the adolescent period as a developmental consequence. Unfortunately, there are no longitudinal data available in the literature to evaluate whether or not such a pattern exists as part of developmental trajectories among children with repaired cleft palate. In contrast, other research has shown that younger children generally have longer VOTs than older children or adults [13, 20]. This directional pattern is in agreement with a related line of developmental research concerning speech durations and duration variability, which has shown a general trend that duration variability decreases as duration decreases with age [26–29]. If an overall decrease of VOT across age is the direction dictated by motoric maturation, the result from the present study may imply that a compensatory overshoot behavior of lengthened VOTs, presumably acquired at a young age [8, 9], not only persists but also is further exaggerated during adolescence, toward the direction of maximizing the voicing contrast. Reduced VOT variability lends additional support to the view that longer VOTs in OC relative to YC may be compensatory in nature, which has been stabilized over time within these children's pro-

duction of voiceless stop consonants. Although data from the present study cannot ascertain the source of VOT differences between YC and OC, children from both groups demonstrated VOTs for voiceless stop consonants that remained markedly lagged and clearly distinct from those for voiced counterparts. Additionally, OC demonstrated VOT means of 67, 80, and 84 ms for /pa/, /ta/, and /ka/, respectively. While no statistically significant differences were found in VOTs among three voiceless stops, the increasing VOT pattern, as the place of constriction moves from the anterior (i.e., bilabial) to the posterior (i.e., velar) part of the oral cavity, conformed to the known VOT variation related to place of constriction as reported in previous studies [5, 12, 30–32].

The pattern of VOT variability that was significantly smaller in OC than YC observed in the present study is in agreement with previous research that reported a decreasing VOT variability as a function of age in typically developing children [18, 20, 33]. VOT variability across different age groups (5 through 13 years) was first reported by Whiteside et al. [18]. Based on a plateau in the decreasing pattern of VOT variability, particularly noted with the age groups of 11 and 13 years for voiceless stop consonants, Whiteside et al. [18] formulated a hypothesis that children may acquire adult-like fine temporal coordination patterns of speech by approximately 11 years old. Supported by data from a recent cross-sectional study [20], VOT variability indeed appears to decrease with age. Although the precise age at which children with repaired cleft palate reach a plateau in the decreasing pattern of VOT variability cannot be ascertained by the present study, our findings provide evidence that VOT variability decreases with age in these children, presumably a consequence of refinement and maturation of speech motor skills. More importantly, our data suggest that such a developmental pattern remains salient in children with repaired cleft palate.

The absence of age-matched controls in the present study challenges data interpretation, especially regarding to what extent VOT variability patterns of children with repaired cleft palate would be similar or dissimilar to those of typical peers. Although beyond the scope of this report, a supplemental analysis was performed to provide directions for future research in which the VOT variability means of YC (6–11 years) and OC (12–18 years) observed in the present study were compared to those reported in Yu et al. [20]. VOT variability of typical children decreased from 16.9% at age 6 years to 10.6% at age 11 years for the production of /pa/ [20]. A one-sample *t* test was used to test if the VOT variability mean of YC (27%)

observed in the present study was different from that of typical 6-year-olds (16.9%) [24] as a liberal estimate. Results showed that the VOT variability mean of YC with repaired cleft palate was significantly greater ($t(13) = 2.452$; $p < 0.05$) by 10.4% (95% confidence intervals [95% CI], 1.2% to 19.6%) than that of typical 6-year-olds. Data from Yu et al. [20] further showed continued decreases in VOT variability from 9.6% at age 12 years to 5.7% at age 18 years for the production of /pa/. An additional one-sample t test was used to test if the VOT variability mean of OC (16%) observed in the present study was different from that of typical 12-year-olds (9.6%) [20] as a liberal estimate. The VOT variability mean of OC with repaired cleft palate was found to be significantly greater ($t(8) = 2.717$; $p < 0.05$) by 6% (95% CI, 9–11.0) than that of typical 12-year-olds (9.6%) from Yu et al. [20]. Greater-than-normal VOT variability observed in children with repaired cleft palate may suggest slow/delayed mastery of timing coordination between laryngeal and supralaryngeal events. It is very plausible that compensatory maneuvers adopted by children (e.g., increased respiratory drive or laryngeal resistance [8–11]) or the presence of inadequate VP valving and severity levels may further increase cross-speakers VOT variability and complicate interpretations of VOT variability.

A better understanding of the developmental acquisition of voicing contrasts and its interplay with compensatory maneuvers in children with repaired cleft palate will shed light on clinical management, especially with regard to therapeutic approaches. Whether it was a developmental consequence, a compensatory maneuver employed, or a combination of both, both YC and OC with repaired cleft palate in the study were able to produce long-lag VOTs for voiceless stop consonants, and production of long-lag VOTs appeared to be further exaggerated and stabilized during the adolescent period. There may be circumstances, however, in which production of voiceless stops with long-lag VOTs may be challenged, for example when these children are to use increased speaking rate, which has been reported as a factor reducing VOTs within a given speaker [30, 31]. Thus, identification and use of adequate speaking rate that do not compromise voicing contrasts may be a topic of clinical interest. In addition, therapeutic approaches should be designed such that compensatory behaviors that excessively overwork any speech production subsystem should be carefully monitored and eliminated if necessary.

Despite the primary focus on age group comparisons of VOT and VOT variability among children with repaired cleft palate, the absence of a control group remains

a clear limitation of the present study. No direct comparisons can be made between the few studies in the literature that have explored VOT patterns in children with repaired cleft palate, partly due to the known VOT variations across different place of articulation for target consonants [5, 12, 32], language-specific VOT continua [5, 34], and speaker-related factors, such as age, sex, or clinical heterogeneity [7–9, 12, 20, 35, 36]. Caution should be also taken when interpreting our findings given that our data may not be a valid representation of children with speech/resonance problems secondary to a history of cleft palate (Table 1). In addition, discussions on VOT and VOT variability were confined to two age groups with a relatively wide age range for each group. Future research with a large sample size while carefully controlling for age, sex, and severity of hypernasality may elucidate different sources of VOT variation in children with repaired cleft palate. Another limitation pertains to the lack of descriptions on voice characteristics of the participating children. While the VOT difference of 10 ms between YC and OC was statistically significant, its clinical significance, especially on the perceptual domain, is unclear. It is not uncommon that individuals with a history of cleft palate develop dysphonic symptoms [37–41]. Given that laryngeal adductory gestures vary across different voice onset types [42], VOT patterns of children with repaired cleft palate should be discussed with laryngeal behaviors taken into account in future studies.

In conclusion, age was found to have significant effects on VOT and VOT variability patterns in children with repaired cleft palate. Results showed that OC had longer VOT and less VOT variability compared to YC, suggesting that production of long-lag VOTs appeared to be further exaggerated and stabilized during the adolescent period. This is the first to describe the VOT and VOT variability patterns in older children/adolescents with repaired cleft palate. A future study is necessary to determine different sources of VOT and VOT variability (e.g., compensatory gestures, developmental attributes) and the interplay of different sources of variations in children with a history of cleft palate, which may shed light on clinical management.

Disclosure Statement

The author has no conflicts of interest to disclose.

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