VOWEL SPACE AREA CHANGES IN CHILDREN WITH DYSARTHRIA

Jiyoung Choi[1], Kyung Hae Hwang[1], Erika S. Levy[1]

Teachers College, Columbia University, USA
jyc2173@tc.columbia.edu, khh2106@tc.columbia.edu, elevy@tc.columbia.edu

ABSTRACT

Increasing speech intelligibility is an essential treatment target for children with dysarthria secondary to cerebral palsy. Vowel space area (VSA) is associated with intelligibility in dysarthria. The speech cues “speak with your big mouth” and “speak with your strong voice” have been found to increase intelligibility in this population. This study examined changes in VSA in response to speech cues in children with dysarthria. We further investigated whether dysarthria severity impacted the VSA changes. Thirteen children with dysarthria were cued to speak with a “big mouth” or “strong voice.” First and second formants were measured from four corner vowels in carrier sentences. Preliminary results show a trend toward increased VSA, with children with mild dysarthria exhibiting the greatest changes. Therefore, cueing children with dysarthria, especially mild dysarthria, to speak with their “big mouth” and/or “strong voice” may increase their VSA and thus, potentially contribute to increasing their intelligibility.

Keywords: childhood dysarthria, cerebral palsy, vowel space area, speech cues

1. INTRODUCTION

Motor speech disorders refer to disorders resulting from neurologic impairments that affect the motor planning/control of speech movements and the execution of speech. Dysarthria is a motor speech disorder caused by muscle weakness and/or coordination/control difficulties due to neurological damage. It may be characterized by imprecise articulation, slow speech rate, reduced vocal intensity, and other variable deficits [1]. Cerebral palsy (CP) is one of the most common causes of dysarthria. CP is a congenital, heterogeneous disorder that affects the ability to move and/or maintain balance and posture. It is the most common neuromotor disability in childhood, with approximately 1 in 345 children in the US identified with CP [2].

Dysarthria is characterized by distinctive temporal and spectral speech features, often including reduced articulation rate, reduced second formant (F2) range of diphthongs, as well as overall atypical vowel formant structure when compared to the speech of typically-developing children [3], [4]. Reduced intelligibility is therefore a common characteristic in children with dysarthria due to cerebral palsy (CP) [5]. Thus, increasing intelligibility is an essential goal in speech treatment for this population [6]–[10] In addition, vowel space area (VSA) has been a common indicator of speech intelligibility in dysarthria. Previous work has found that compared to typically-developing children, those with dysarthria demonstrate smaller VSA, which is associated with reduced intelligibility [11]–[14].

Findings from studies on adults with Parkinson’s disease (PD) indicate that VSA increases in response to various speech cues (e.g., clear, loud, slow, over-enunciate) relative to habitual speech [15], [16]. It is also reported that VSA increases and is associated with greater speech intelligibility post-treatment in adults with PD through Lee Silverman Voice Treatment [17], [18]. Moreover, changes in VSA and listeners’ vowel ratings have been examined following speech treatment in adults with PD [18]. In comparison to pre-treatment, VSAs were larger post-treatment, with higher vowel goodness ratings.

In children with dysarthria, VSA changes following speech cues or treatment are understudied. Previous studies examined F1 and F2 changes in individual vowels (e.g., /æ/ and /ɑ/) when children with dysarthria were cued to speak with a “big mouth” or “strong voice” [19] or following Speech Intelligibility Treatment [9], which incorporates these cues in a three-week treatment program. The “big mouth” cue aims to increase VSA and articulatory excursion, and the “strong voice” cue aims to increase vocal intensity, and therefore to bring about amplitude increases across speech production systems [9]. Because VSA is a key predictor of speech intelligibility in childhood dysarthria [13], it is important to examine whether providing speech cues for children with dysarthria increases their VSA, as well as the relationship between any VSA changes and intelligibility changes. Such information may provide direction for optimizing speech treatment strategies and may shed light on mechanisms behind speech intelligibility improvement in this population. Findings may also help determine whether factors such as dysarthria severity affect intelligibility gains.

Participants	Age	Sex	Cerebral palsy diagnosis	GMFCS*	Dysarthria Severity	Receptive Language Skills**	
CP01	12;0	M	mixed	V	Severe	63th	average
CP02	7;4	F	mixed	III	Mild	<1st	very poor
CP03	12;8	M	spastic	V	Moderate	9th	below average
CP04	15;7	M	mixed	V	Mild	<1st	very poor
CP05	14;7	M	spastic	II	Mild	50th	average
CP06	16;1	M	spastic	I	Mild	37th	average
CP07	10;9	M	spastic	II	Mild	25th	below average
CP08	5;2	M	spastic	IV	Moderate	25th	below average
CP09	12;5	F	spastic	IV	Severe	<1st	very poor
CP10	13;2	F	spastic	IV	Moderate-Severe	2nd	very poor
CP11	9;7	M	mixed	II	Mild	37th	average
CP12	5;1	M	spastic	IV	Mild	37th	average
CP13	14;1	M	ataxic	II	Mild-Moderate	<1st	very poor

Table 1: Demographics of children. Gross Motor Classification System (GMFCS)[20]*. M = male; F=female. Percentile rank obtained from the Test of Auditory Comprehension of Language (TACL) or Clinical Evaluation of Language Fundamentals-5 (CELF-5)**.

The current study examined the changes in vowel space area (VSA) when children with dysarthria were cued to speak with their "big mouth" or their "strong voice". It was hypothesized that VSA in the "big mouth" condition would be larger than VSA in their habitual speech. The "strong voice" cue was also expected to increase VSA, albeit less so than the "big mouth" cue [9], [19]. We further investigated whether dysarthria severity impacted the VSA changes. It was hypothesized that children with mild dysarthria would demonstrate greater VSA changes than those with moderate or severe dysarthria [9], [19].

2. EXPERIMENT

2.1. Participants

A total of 14 monolingual English-speaking children with dysarthria secondary to CP participated in the study. One child's data were excluded due to incomplete tasks. Therefore, data from a total of 13 children are reported in the study (mean age = 11;4 yrs; range 5;1–16;1 yrs; 3 females, 10 males). Subtypes of cerebral palsy and dysarthria severity varied. Dysarthria severity level was determined by two certified speech-language pathologists based on independent assessments of speech intelligibility [21], [22]. Any disagreements of judgment were reconciled by consensus. All children presented with normal hearing. Table 1 summarizes participant characteristics.

2.2. Stimuli

The stimuli in this study were sentences (i.e., "They say CVC again") containing American English CVC words (beat, bat, boot, and pot), representing the four corner vowels (/i/, /æ/, /u/, and /ɑ/, respectively). Sentences were pre-recorded by a monolingual American English female adult in preparation for presentation to the children with dysarthria, who repeated the sentence. Each sentence was recorded in three speech conditions: habitual speech, and in response to "big mouth", and "strong voice" cues. A total of 156 stimuli (13 children x 4 sentences including four corner vowel-representing words x 3 speech conditions) were analyzed.

2.3. Procedure

The experiment was conducted in the children’s homes with instructions delivered virtually by researchers and the procedure monitored by Zoom video [23]. Recording equipment had been sent to the child’s home. The child’s parent placed a Countryman EMW Lavalier microphone on the child’s forehead, 8cm from the child’s lips. The pre-recorded sentences were played by the researcher and transmitted through Zoom. The children were asked to repeat the pre-recorded sentences. The habitual condition was followed by the cued conditions, with the “big mouth” and “strong voice” conditions counterbalanced. For the habitual condition, children were simply asked to repeat what they heard. For the “big mouth” condition, children were instructed to speak with their “big mouth,” and for the “strong voice” condition, with their “strong voice”. Verbal modeling was provided throughout the task if necessary. After the experiment, the parents returned the recording equipment including the sound card with the children’s audio recordings. Then researchers downloaded the children’s audio recordings from the sound card.

2.4. Analysis of VSA metrics

For VSA analysis, the CVC words (beat, bat, boot, and pot) were extracted from recordings of the carrier sentences produced by the children. and quadrilateral VSA was examined [4]. First, the onset and offset of each corner vowel (/i/, /æ/, /u/, /ɑ/) and the total vowel duration (ms) were measured. Next, the first and second formants (F1 and F2) were manually extracted at the temporal midpoint of each vowel using 25-ms window wideband spectrograms and linear predictive coding (LPC) spectra. F1 is associated with tongue height, and F2 is related to tongue forwardness/backness [24]. The quadrilateral VSA was calculated (Hz^2) by means of Heron’s formula and Euclidean distance measurement [4], [16] via ‘phonR’ package [25]. Figure 1 represents an example of the configuration of VSA.

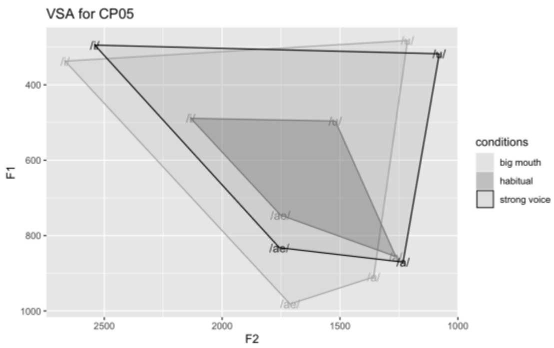

Figure 1: Vowel Space Area (VSA) for a participant CP05 with mild dysarthria.

2.5. Statistical analysis

Due to the small number of participants in the study, $p = .05$ was considered statistically significant [12]. To examine the VSA change following the speech cues within the single child, repeated-measures analyses of variance (ANOVA) with Bonferroni-corrected post hoc pairwise comparisons were utilized [9], [19]. Furthermore, relationships between speech conditions and each severity group were examined descriptively because of the small number of children within each severity group.

3. RESULTS

Preliminary results indicate a trend toward increased VSA in both cued conditions relative to habitual speech, except in one child with severe dysarthria (See Table 2). Moreover, VSA gains were greater following the “big mouth” cue than following the “strong voice” cue. There were four cases in which VSA increased in response to only one speech cue, compared to habitual speech; i.e., in two children, VSA increased only in “big mouth” condition and for two children, only in “strong voice” condition. Visual inspection further indicates that for 10 of the 13 participants, VSA increased following at least one of the speech cues, whereas for 2 (CP03, CP09), VSA decreased.

As can be seen in Figure 2, the linear mixed-effects model revealed a significant main effect of speech cues in VSA, $F(1, 12) = 47.023$, $p < .001$. Post hoc Bonferroni-corrected pairwise comparisons indicated a significant increase in VSA in the “big mouth” condition relative to habitual speech (mean difference = 127618.54, 95% CI [3688.34, 251548.73], $p < .05$). No significant differences were found between the “strong voice” condition and the habitual condition (mean difference = 55186.31, 95% CI [−43421.16, 153793.77], $p > .05$).

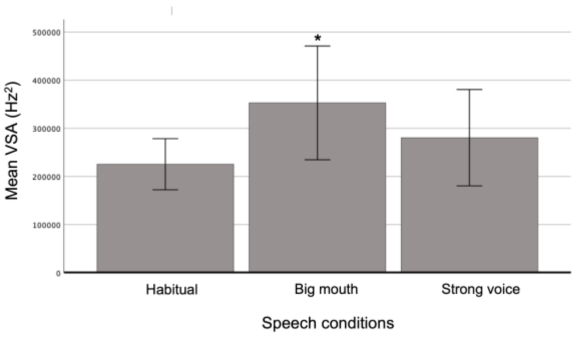

Figure 2: Mean Vowel Space Area (VSA) across 13 children with dysarthria in three speech conditions. Standard error bars are included. *$p \leq .05$.

Additionally, VSA changes varied as a function of dysarthria severity. Visual inspection suggests that in children with mild dysarthria, VSA was larger following either speech cue when compared to the children's habitual speech. Noticeable increases of VSA following either cue were observed in three children with mild-moderate and moderate dysarthria. For the 2 children with moderate dysarthria, one child showed significant VSA gains following both speech cues, whereas the other child showed no VSA changes across conditions. The child with moderate-severe dysarthria demonstrated VSA increases following both speech cues. For the 2 children with severe dysarthria, VSA increased in "big mouth" cue in one child, but no increase was found following either cue in the other child.

Partici-pants	**Vowel space area (Hz^2)**			**Dysar-thria severity**
	Habitual	**Big mouth**	**Strong voice**	
CP01	180569	240827	176776	Severe
CP02	184852	238814	214257	Mild
CP03	241868	116860	224397	Moderate
CP04	145460	216182	207569	Mild
CP05	247062	600296	566227	Mild
CP06	253046	296042	163456	Mild
CP07	213545	193151	264911	Mild
CP08	216040	424042	347689	Moderate
CP09	220998	151468	110574	Severe
CP10	73975	217720	191155	Moderate-Severe
CP11	200882	545829	269332	Mild
CP12	497715	829154	747288	Mild
CP13	254101	518769	163904	Mild-Moderate

Table 2: Vowel Space Area (VSA) in three speech conditions.

4. DISCUSSION

When children with dysarthria were cued to speak with a "big mouth" or "strong voice," a trend toward increased VSA was revealed in both cued conditions. VSA increased significantly, particularly in children with mild dysarthria. These findings suggest that speech cues targeting articulatory excursion and increased vocal intensity may positively impact VSA in children with mild dysarthria. Because VSA is an important predictor of speech intelligibility in children with dysarthria [12], [13], targeting VSA directly (e.g., "big mouth") or indirectly (e.g., "strong voice") may lead to improvements in intelligibility, especially in children with mild dysarthria.

However, while the majority of the children showed increased VSA following the speech cues, VSA of 2 of 13 children (CP03, CP09) was smaller following both cues than in their habitual speech. This result was unexpected, given that in Levy et al.'s cueing study [19], all 8 of the children with dysarthria increased intelligibility when responding to these cues. Our result might be a consequence of noise in the audio recordings. Thus, acoustic predictors of intelligibility changes in children with dysarthria require further investigation and may vary depending on the child's speech characteristics.

Future directions include determining adult listeners' perception of the children's word and sentence productions to more directly assess the impact of speech cues and VSA on intelligibility.

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