Acoustic variability in the speech of children with cerebral palsy

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摘要

本研究檢視兩對四歲腦性麻痺孩童和正常孩童的構音聲學變異性，研究項目包含母音空間、聲調和語速。研究語料爲四位孩童的四卷錄音檔，內容爲孩童的圖卡唸名和與大人的自然對話。分析結果顯示：1) 母音空間：腦性麻痺孩童的母音空間比正常孩童小，且共振峰頻率分佈較爲散亂且不穩定；2) 音高：腦性麻痺孩童除了在發音上會花較多的時間外，其聲調也較正常孩童不穩定；3) 說話語速：腦性麻痺孩童的語速和清晰度皆較低。這些初步的研究結果可再進一步驗證，腦性麻痺孩童聲學變異性特徵可提供臨床語言治療及評估的方向參考。
關鍵字：華語幼童、腦性麻痺、母音空間、聲調、語速

Abstract

This study examines the acoustic variability in four 4-year-old children: two with cerebral palsy (CP) and two typically developing (TD). One recording from each child, collected from the picture-naming task and spontaneous interaction with adults was analyzed. Acoustic vowel space, pitch and speech rate in their production were investigated. Study findings indicated the following: 1) children with CP have a smaller vowel space than TD children, and there was a scattered distribution of the formant frequencies in CP; 2) children with CP tend to spend more time producing the utterances and their production of tones was unstable; and 3) both the speech rate and speech intelligibility in CP were lower. Future studies are needed to verify these preliminary findings. The variability features in the production of children with CP provide important references in speech therapy.
Keywords: Mandarin-speaking children, cerebral palsy, vowel space, fundamental frequency, speech rate

1. Introduction

Cerebral palsy is a common speech motor disability in children, and an umbrella term to indicate a neurologic developmental condition that affects individuals from early childhood throughout their lifespan [1]. Due to the neurologic factors, children with cerebral palsy tend to have several types of speech deficits. According to a previous study [2], 60% of children with CP have some type of speech deficits, among which dysarthria, the most common speech disorder found in individuals with CP, has received more attention. This study focuses on the acoustic aspects of dysarthria: vowel space, pitch, and speech rate. Vowel space is an acoustic measure that indicates the jaw's coordination and the tongue's controlling ability [3]. Because of poor muscle coordination, individuals with dysarthria tend to have a smaller vowel space, which influences the accuracy of articulation and reduces the intelligibility of their speech. Moreover, because dysarthric speakers have a hard time controlling their respiratory and the laryngeal mechanisms, it is difficult for them to produce correct tones, which plays an important role in the intelligibility of tonal languages ([2], [4], [5]). Furthermore, the stability of the speech rate affects listeners' intelligibility, but dysarthric speakers usually present a rate disturbance [6]. Therefore, these three acoustic measures are vital to the speech of the individual with dysarthria. By analyzing these three measures, this study provides a preliminary index of cerebral palsied speech and a direction for speech-language intervention.

2. Literature review

2.1 Acoustic vowel space

Many researchers have used vowel space as an index for the size of the vowel articulatory working space, the accuracy of vowel articulation, and the tongue's controlling ability ([3], [7]). Moreover, the influences of dysarthria and unclear speech on the sizes of vowel areas and the relationship between vowel space and speech intelligibility were investigated ([8], [9]). According to a previous study [3], vowel area formed by the 1st formant (F1) and the 2nd formant (F2) can reflect the control ability and mobility of the tongue. In other words, if the mobility of the tongue is abnormal, the F1-F2 area would be reduced. In Higgins and Hodge's [10] study with 12 participants, six children had been diagnosed with dysarthria, and six were controls. They compared the vowel spaces of the corner vowels /a/, /i/, /æ/ and /u/ produced by the two groups and found that the vowel space of children with dysarthria is smaller. Jeng [9] indicated that the vowel quadrilaterals of the controls are more uniform, while CP groups' vowel quadrilaterals are variable because of the non-uniform F1-F2 formant values. People with dysarthria tend to speak at a slower rate or at a louder volume to make their speech intelligible, which may expand the vowel space [11]. In clinical treatment, controlling the speech rate is widely employed by speech therapists, and the effects of slowing the speech rate on vowel space and speech intelligibility was discussed in the previous study ([5], [9], [11]). Therefore, it can be inferred that the abnormality of vowel space is a critical reason for the inaccurate articulation and the reduced speech intelligibility of people with CP.

2.2 Pitch

Dysprosody, where the control of prosodic variables such as fundamental frequency (Fo) or pitch is impaired, is a common feature of dysarthria [12]. According to Ciocca et al. [2], in tonal languages, such as Cantonese, tonal-level contrast was the second most problematic phonetic contrast that influenced speech intelligibility.

In Mandarin Chinese, there are four dominant tones: high-level (tone 1), high-rising (tone 2), low-falling-rising (tone 3), and high-falling (tone 4) [13]. According to Han et al. [14], tone or pitch of each monosyllable makes meaningful contrasts. For instance, changing the four tones of the same syllable, *ma*, will create meaningful contrasts: "mother" (tone 1), "hemp" (tone 2), "horse" (tone 3), and "scold" (tone4). Therefore, pitch is central to the intelligibility of tonal languages.

In order to produce different tones to make meaningful contrasts, speakers alter the tension of the vocal folds and the amount of air flowing from the lungs [2]. However, because dysarthric speakers have difficulty controlling the respiratory and the laryngeal mechanisms, they cannot always produce correct tones ([2], [4], [5]). Bunton et al. [12] found that English-speaking dysarthric adults tended to decrease the duration of their tone units, or produce fewer words in a tone unit. In addition, the range of Fo of dysarthric speakers is restricted. Furthermore, Cantonese dysarthric speakers showed errors in Fo level and/or Fo contour due to the lack of control of laryngeal mechanism [2].

2.3 Speech rate

Due to the neuromuscular factors, it is not surprising that individuals with dysarthria tend to have a slower and more unstable speech rate ([3], [6], [15], [16]). Many researchers have tried to associate speech rate and speech intelligibility to further discuss the complete index of one's speech performance [17]. The previous study [4] stated that slower speech rate of individuals with cerebral palsy may contribute to higher speech intelligibility, which also serves as an aid to their communication efficiency. In contrast, other studies have found no significant correlation. Turner, Tjaden, and Weismer [8], by having dysarthric subjects read the passages at habitual, fast, and slow speaking rate, concluded that there is no specific correlation between these two issues. Therefore, there is still no agreement on the relationship between speech rate and speech intelligibility. Whether the slower speech can be a compensatory strategy to increase intelligibility remains unknown. This study explores the relationship between speech rate and speech intelligibility in spontaneous speech production in 4-year-olds with cerebral palsy, and answers the following questions: (1) Is the speech rate of the children with dysarthria slower than that of typically developing children? (2) How is speech rate related to speech intelligibility?

3. Methodology

3.1 The participants

Four children participated in this study: two with cerebral palsy (CP1 and CP2, mean age 52.3 months) and two with no specific medical history (TD1 and TD2, mean age 54.8 months). The tables provide background information of CP1 and CP2.

Table 1. Descriptive data of the two CP subjects

Subject	Gender	Months	Classification	Type of CP	Severity of impairment
CP1	Male	48.3	Dyskinetic	Quadriplegia	Moderate
CP2	Male	56.3	Other	Quadriplegia	Severe

Table 2. Descriptive data of the two TD subjects

Subject	Gender	Months
TD 1	Male	54.5
TD 2	Male	55.1

All of the subjects are male, in order to avoid any potential gender differences in pitch, and are have normal hearing and intelligence. The two CP subjects were recruited from a hospital. CP1 has the medical diagnosis of dyskinetic quadriplegia with moderate CP. He has been diagnosed with borderline language delay on the basis of Preschool Language Scale-Chinese Version (PLS-C), and has received language therapy. CP2 has the medical diagnosis of quadriplegia with severe CP. He received education in a special education center, but he has never received language therapy. The data of TD subjects were taken from a large-scale study of longitudinal phonetic development.

3.2 Data collection

CP1's data were collected in lab with less noise disturbance, while the data of CP2 and the two TD children were collected in their homes. Although the locations were different, the same recording equipment was used. A SHURE Wireless microphone system was linked to TASCAM DR-100 recorders for the purpose of sound recording. During the 50-minute observation period, speech productions in picture naming task were recorded, and the Peabody Picture Vocabulary Test-Revised (PPVT-R) was used to provide a quick assessment of the speech and language ability.

3.3 Data analysis – acoustic vowel space

The first 50 utterances with clear quality were transcribed and analyzed with the time-frequency analysis software program, TF32. Vowel formant frequencies were determined with reference to spectrogram, LPC, and FFT with Hillenbrand, Getty, Clark, and Wheeler [18] as the range reference of formant frequencies. F1 and F2 values and bandwidth were measured. Vowels with unrecognized formant patterns or with large bandwidth (larger than 1000Hz) were discarded.

All F1 and F2 values of vowels were normalized. The procedure of normalization is intended to reduce the differences caused by extrinsic vowel formant values and remaining the phonological distinctions among different vowels ([19], [20]). The differences of vowel productions of CP and TD were analyzed in three aspects: the F1 and F2 values of individual vowels /i/, /a/, /u/, /ə/, /ɛ/, and /ɔ/, standard deviation of formant frequencies, and vowel space. Overall F1-F2 vowel spaces were calculated to examine the data diversity, and the vowel space formed by the three corner vowels /i/, /a/, and /u/ were captured to illustrate the mobility and control ability of tongue and jaw.

3.4 Data analysis - pitch

Pitch values of bi-syllabic or tri-syllabic words were analyzed based on four dominant tones in Mandarin Chinese: high-level (tone 1), high-rising (tone 2), low-falling-rising (tone 3), and high-falling (tone 4) [13]. However, in Mandarin spoken in Taiwan, the low-falling-rising tone or dipping tone (tone 3) is always replaced by low-falling tone. The first 50 intelligible and less disturbed utterances were selected for pitch analysis. The same procedure was administered to all four children.

TF32, an acoustic analysis program, was used to estimate fundamental frequency (Fo), mean standard deviation of Fo, mean tone duration (TU), mean slope (in Hz/ms), and the maximum and minimum values of Fo. In addition, the beginning point (BP) and the end point (EP) were measured for tone 1 and 4; the beginning point (BP), the inflectional point (IFP), and the end point (EP) were measured for tone 2 and tone 3.

For slope of tones, two functions were used to measure.

Function 1: SLP1 (Tone1 and 4) = (EP-BP)/ ($\overline{\mathrm{EP}-\mathrm{BP}}$)

Function 2: SLP2 (Tone2 and 3) = (IFP-BP)/ ($\overline{\mathrm{IFP}-\mathrm{BP}}$)

SLP3 (Tone2 and 3) = (EP-IFP)/ ($\overline{\mathrm{EP}-\mathrm{IFP}}$)

Note that in Slope Function 2, tone 3 was in fact the low-falling tone.

3.5 Data analysis – speech rate

In speech rate, the target data were the phrases and sentences produced by the four children in spontaneous interaction. To examine speech intelligibility, the target data were 50 randomly chosen words from the picture-naming task in the same recordings. The following principles are based on the data collection procedures in [4].

(1) Syllables per minute (SPM): one judge listened to the phrases and sentences, transcribed the content syllable by syllable, and counted the number of the syllables. SPM is obtained by calculating the total number of the syllables divided by the time duration, and multiplying the quotient by 60. In the case of spontaneous speech, the intra-sentence pauses were included, but the inter-sentences pauses were not.

(2) Intelligible syllables per minute (ISPM): ISPM is acquired by counting only the number of the intelligible syllables divided by the duration, and multiplying the quotient by 60. Ten

percent of the data were re-analyzed by the second judge. The inter-judge was allowed to listen to the data again, and to the relevant context but no more than twice. The result of inter-judge reliability is 86.2%, which exceeds the standard proposed by Kassarjian [21].

Speech intelligibility: Three judges were recruited to transcribe productions of 50 words of each child in the picture naming tasks. The judges could only listen once and then transcribed what they heard. All the judges worked alone, and at their own pace. The total number of correctly transcribed syllables was divided by the total number of the syllables of the 50-word list. Mean intelligibility from the three judges was calculated as speech intelligibility of each child.

4. Results and discussion

4.1 Acoustic vowel space

Frequency of occurrence

The following results compare CP and TD group in vowel accuracy and the occurrence of main vowels (/i/, /a/, /u/, /ə/, /ɛ/, and /ɔ/).

Table 3. The occurrence of main vowel in the four children

Vowels	CP1	CP2	TD1	TD2
/i/	21.33%	17.39%	22.95%	25.86%
/a/	22.67%	21.74%	22.95%	29.31%
/u/	10.67%	15.94%	21.31%	13.79%
/ə/	22.67%	24.64%	11.48%	8.62%
/ɛ/	14.67%	10.14%	11.48%	13.79%
/ɔ/	8%	10.14%	9.84%	8.62%

Table 3 shows that vowels /i/ and /a/ have a high frequency of occurrence, and vowel /ɔ/ shows a lowest frequency in both CP and TD children. Furthermore, both CP1 and CP2 show a high frequency of occurrence in vowel /ə/ during their picture naming task.

Table 4. The accuracy of each main vowel in the four subjects' vowel production

Vowels	CP1	CP2	TD1	TD2
/i/	100%	80%	100%	100%
/a/	100%	100%	100%	75%
/u/	100%	100%	100%	100%
/ə/	80%	25%	100%	50%

Table 4 indicates high accuracy in corner vowels (/i/, /a/, and /u/), while a respectively lower accuracy in vowel /ə/. Comparing to TD children, children with CP show a lower accuracy of vowel production.

Overall vowel spaces

Figure 1 and Figure 2 show the un-normalized and normalized F1 and F2 of the four children. The dots in the figure represent each individual vowel production. In the figure of normalized vowel formant values, the influences of extrinsic vowel formant values are reduced during the normalization procedure.

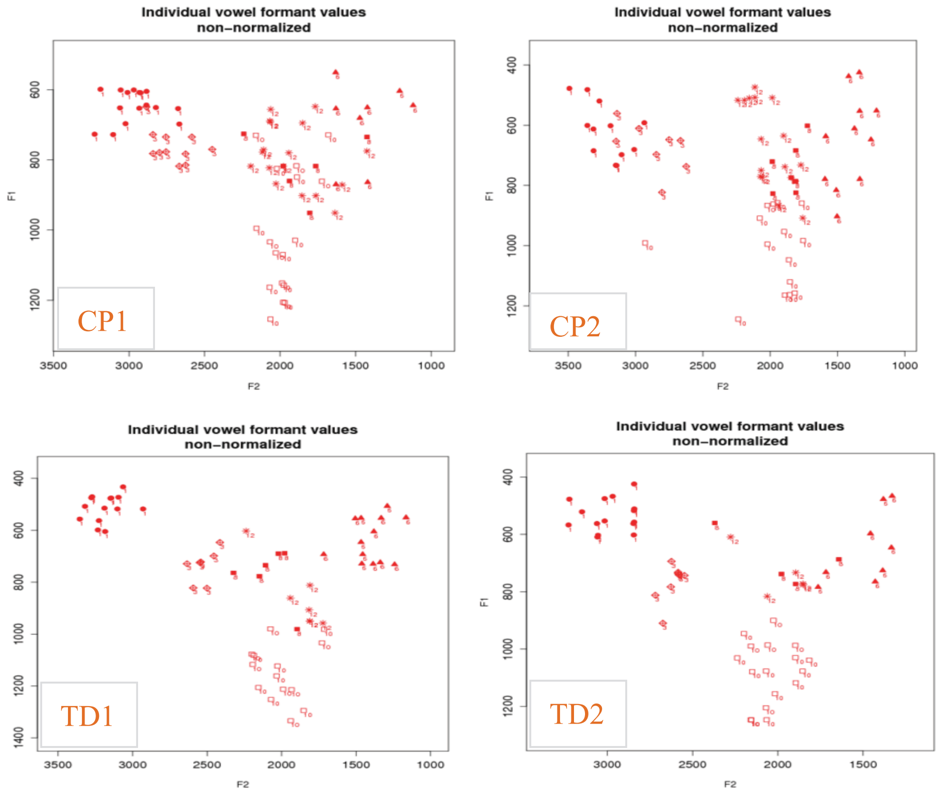

Figure 1. Vowel formant values of CPs and TDs.

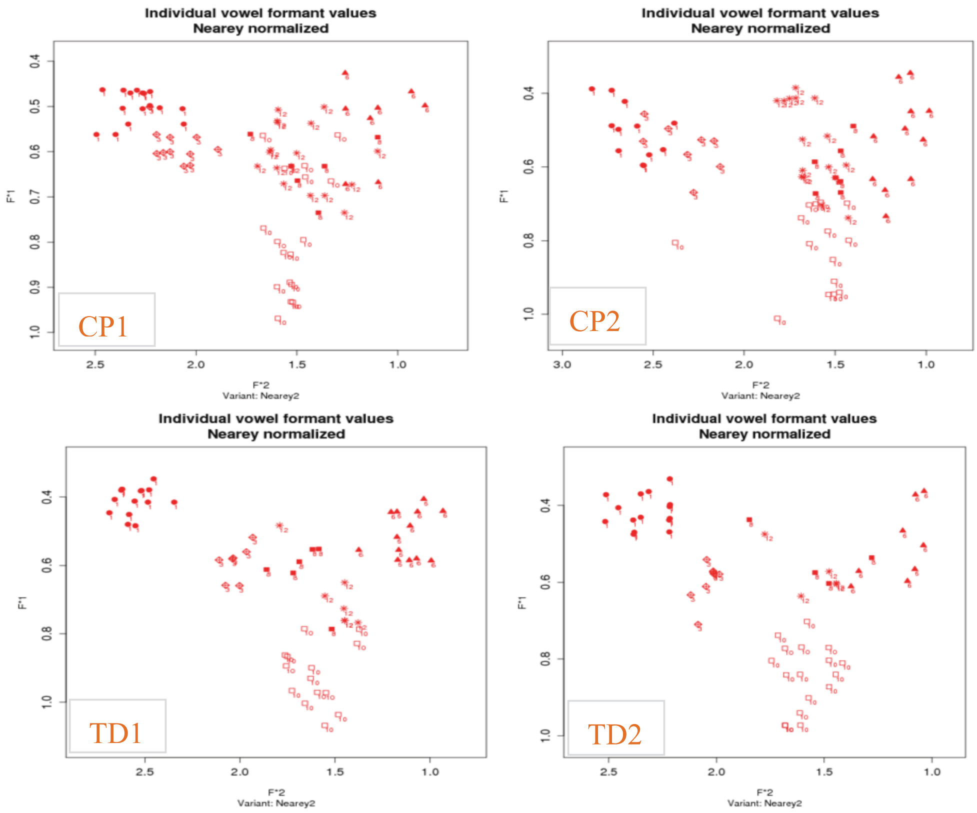

Figure 2. Normalized vowel formant values of CPs and TDs.

As Figure 1 and Figure 2 show, the distribution of CPs' individual vowel formant values is scattered, while that of TDs is more concentrated and more easily recognized. Moreover, the distinction of formant values distribution between central vowels and corner vowels was not clear in CPs.

Individual vowel spaces

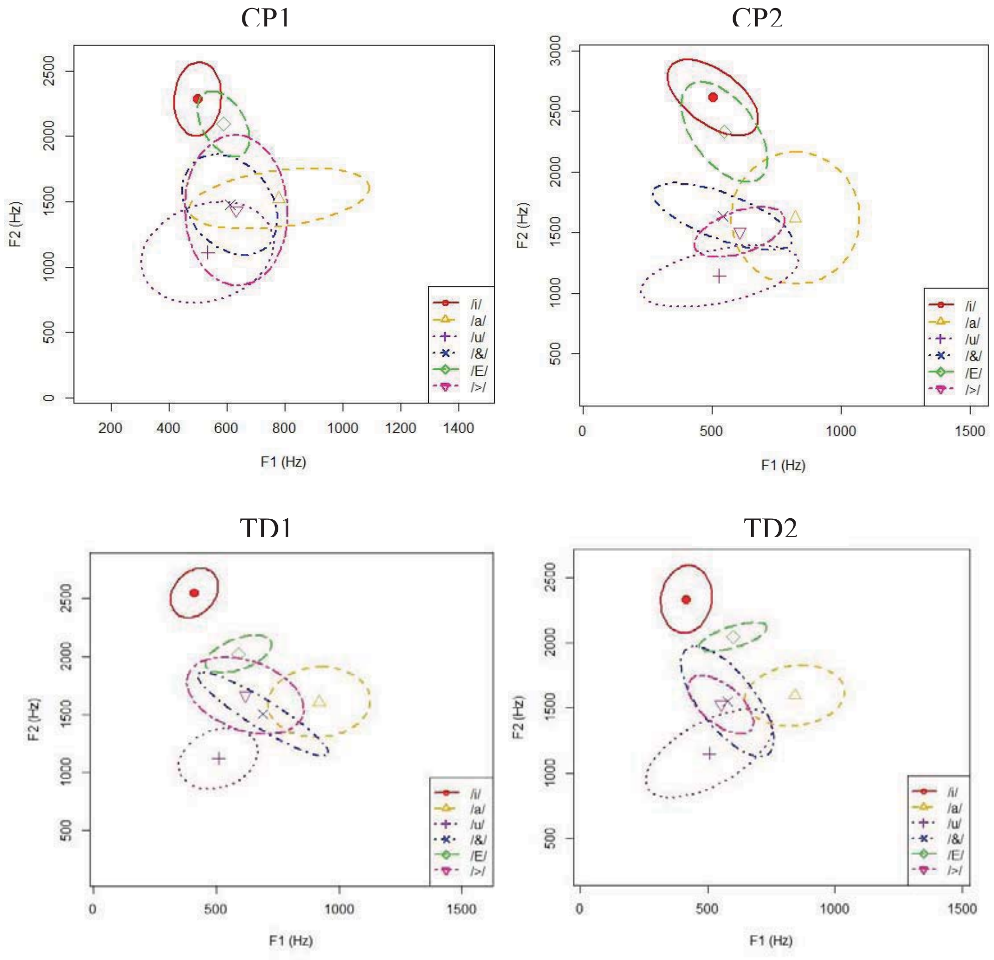

Figure 3. Individual vowel spaces of CP1, CP2, TD1, and TD2.

Figure 3 illustrates that almost all individual vowel spaces in CPs are larger than in TDs, especially in vowel /i/, /a/, and /ɛ/. That is, the deviations of the formant values of CPs are larger than those of TDs. Moreover, the overlapping of individual vowel categories looks more obvious in CP children. Almost all individual vowels overlap with each other, and the positions of vowel spaces gather to the central part, which reduces the distinction between formant values of different individual vowels in CPs.

Table 5. Mean and standard deviation of F1 and F2 values of individual vowels and vowel areas in 4 children

Vowels	CP1		CP2		TD1		TD2	
	F1	**F2**	**F1**	**F2**	**F1**	**F2**	**F1**	**F2**
/i/	497	2285	493	2623	406	2541	413	2333
	†(35.1)	(121.5)	(73.5)	(130.3)	(41)	(90.2)	(43)	(110.1)
/a/	778	1532	814	1618	917	1608	838	1598
	(134.8)	(100)	(106.7)	(233.7)	(88.4)	(128.3)	(84.9)	(100.9)
/u/	539	1112	514	1141	504	1127	491	1142
	(89.6)	(150.9)	(126.3)	(104.7)	(67.9)	(110.6)	(97.8)	(132.6)
/ə/	610	1477	539	1633	691	1503	578	1550

	(70.7)	(166.6)	(116)	(118.9)	(101.4)	(137)	(62.1)	(142.9)
/ɛ/	587 (36.9)	2095 (102.9)	546 (65.3)	2330 (162.2)	591 (51.1)	2023 (61.3)	599 (52.3)	2042 (43.5)
/ɔ/	632 (64.4)	1435 (209.3)	605 (66.4)	1504 (78.2)	619 (86.8)	1664 (120)	552 (43.7)	1525 (75.8)
Vowel area (Hz²)	152761		227608		315555		224572	

† Standard deviation reported in parentheses

Table 5 reveals the mean formant values of CP and TD groups. The CP group shows higher F1 values in high vowels (/i/ and /u/) and lower F1 values in low vowel /a/. There is no obvious difference between CP and TD group in F2 values. Moreover, the CP group shows a larger standard deviation of vowel formant frequencies, which indicates the instability of formant frequencies.

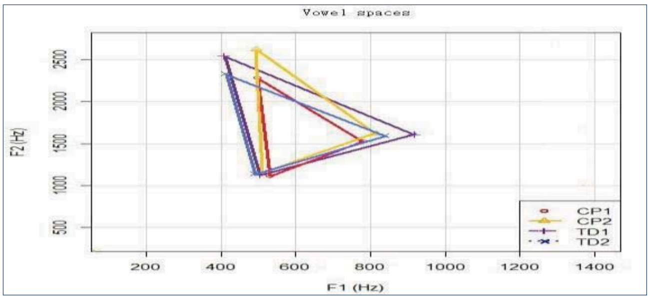

Figure 4. Overall vowel spaces of CP1, CP2, TD1, and TD2.

Compared with the TD group, the CP group shows a smaller overall vowel space. As illustrated in Figure 4, both CP1 and CP2 show a limited range in F1 values, while in F2 values there is no obvious difference between the CP2 and TD groups.

Discussion

The findings indicate that children with CP show a wide and variable range of distribution in individual vowel formant frequencies, while TD children's data of formant values are more concentrated and uniform. This is also found in previous study that the vowel quadrilaterals of controls are uniform, while those of CPs are relatively variable [9]. The deviation in vowel production might be attributable to CPs' abnormal control of the tongue. Moreover, the reduced distinction between corner vowels and other main vowels, and the obvious overlapping of different individual vowel spaces in CP1 and CP2 also indicate a reduced stability in vowel productions. Like what was found in the previous studies ([3], [7], [10]), CP children show a smaller overall vowel space area than TD children.

F1 and F2 values are related, respectively, to the height and advancement of the tongue. In this study, children with CP show a higher F1 in high vowel /i/ and /u/, while showing a lower F1 in mid vowel /ɛ/ and low vowel /a/. That is, they have limited mobility of tongue height. There is thus less of a distinction of F1 values between high and low vowels in children with CP than in TD children [9]. The difference in F2 is less obvious between CP and TD groups. Therefore, the limited F1 range contributes to the smaller vowel space in CP children. This finding is different from [10] which indicated that children with dysarthria used a lower tongue and jaw position to pronounce vowel/a/, and the dysarthric children's smaller vowel spaces were resulted from the reduction of F2 extent instead of F1.

4.2 Pitch

Figure 5 shows the frequency of occurrence of tones. Tone 3 appears to be the least in both groups. In addition, both TDs and CPs produced relatively more tone1 than others.

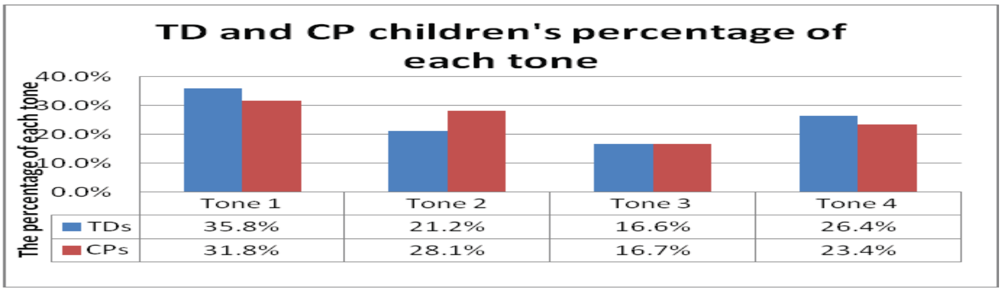

Figure 5. Frequency of occurrence of tones in TD and CP children

The accuracy and substitution patterns

As shown in Table 6, in TD 1, the accuracy rate of tone 1 is the highest among the four tones. The accuracy rate is 96.97% (32 words). The lowest accuracy rate was found in tone 3, which is 54.17% (13 words). TD 1 used tone 1, tone 2 and tone 4 to substitute for tone 3. Moreover, the accuracy rate of tone 4 is higher than tone 2. For TD2, his highest accuracy rate is tone 4 (96.65%; 22 words); while his lowest is tone 2 (70%; 14 words). Moreover, tone 1 appears to be more accurate than tone 3.

For CP1, tone 4 has the highest accuracy rate among the four tones (84.21%; 16 words). The lowest accuracy rate can be seen in tone 3, which is 61.11% (11 words). He used both tone 2 and tone 4 to replace tone 3. Moreover, the accuracy rate of tone 1 is higher than that of tone 2. For CP2, tone 1 has the highest accuracy rate, which is 81.82% (18 words.) The lowest accuracy rate is tone 3, which is 60% (9 words). He used tone 2 and tone 4 to replace tone 3. Moreover, the accuracy rate of tone 2 is higher than that of tone 4.

Table 6. The accuracy and substitution patterns in TD and CP children

Substitution	**TD1**	**TD2**	**CP1**	**CP2**
1→1*	32	30	27	18
1→2*	0	4	5	4
1→3*	0	0	1	0
1→4*	1	1	1	0
2→1*	2	0	0	4
2→2*	18	14	11	15
2→3*	4	6	2	0
2→4*	1	0	1	1
3→1*	3	0	0	0
3→2*	4	2	5	5
3→3*	13	8	11	9
3→4*	4	1	2	1
4→1*	2	0	0	6
4→2*	0	0	1	2
4→3*	2	1	2	1
4→4*	18	22	16	20

* one that substitute for the target tone

Mean duration

Figure 6 shows the mean duration of each tone of the four children. Both TD and CP children's tone 2 is the longest. For CP children, their tone 4 is the shortest; however, TD children's tone 3 is the shortest. Moreover, the mean duration of four tones in CP is about 1.3 to 1.8 times longer than in TD.

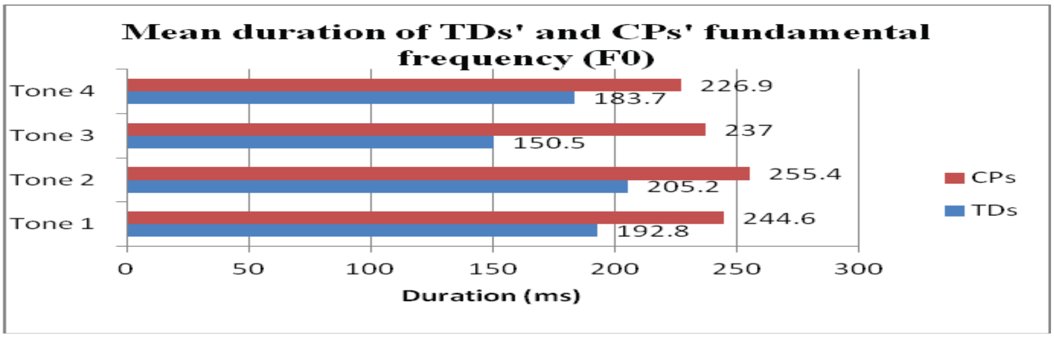

Figure 6. Mean duration of TDs' and CPs' fundamental frequency (Fo)

Mean standard deviation

Table 7 shows the mean standard deviation (SD) of pitch values in each individual tone category in the four children. The higher the SD is, the more unstable the pitch value. In general, the SDs of the pitch values of each tone in CPs are all higher than the SDs of TDs. CPs' SD is about 1.5-1.6 times larger than that of TDs. Therefore, the results indicated that CP children's pitch is indeed more unstable than TD children's, reflecting the lack of speech-motor control of children with cerebral palsy. In addition, for CP children, the SD of their tone 3 is the highest of all, 26.4 Hz, which implies that the pitch development of tone 3 is the most unstable among the four tones. The possible reason is that tone 3 is considered the most complicated in Chinese. According to a previous study [22], tone 3 has a tone notation of 214, which means that tone 3 initially falls from 2 to 1 and then rises from 1 to 4. Therefore, it takes CP children extra energy to produce tone 3, the most difficult one, under the condition that they lack mature speech-motor control. That is why CP children's tone 3 appears to be the most different from that of TD children.

Table 7. Mean standard deviation of fundamental frequency (Fo)

	Tone 1	Tone 2	Tone 3	Tone 4
TDs	13.8	14.6	20.8	20.9
CPs	16.2	22.2	26.4	24.5

Mean slope

In Table 8, we can see that the mean slope of tone 1 in TDs is -0.191 Hz/ms, while CPs' is -0.162 Hz/ms. Both TDs' and CPs' tone 1 tends to go below the level, causing a slight fall for this high-level tone. This lowering of high-level tone can also be found in dysarthric speakers of Cantonese [2] and in hearing-impaired Mandarin-speaking children ([13], [23]). Furthermore, CPs' tone 1 tends to approach the level more closely than that of TDs. The possible explanation is that tone 1 for CP children is actually not a difficult tone to master compared to the other tones. Tone 2 in Chinese has two segments of slope. Tone 2 is a high-rising tone [22]. Before raising the pitch, speakers must temporarily and quickly lower it. Therefore, there are two segments of slope of tone 2. CP children's pitch movement of tone 2 looks very similar to that of TD children. CP children, at first, lowered their tone 2 and then rose up just as TD children did when they produced tone 2. Like the pattern of tone 2, tone 3 has two segments of slope. The duration of the falling-down of tone 3 is longer than that of tone 2. CP children's tone 3 is more monotonous than that of TD children's because their slope, either from BP to IFP or from IFP to EP is closer to the level. The mean slope of TD and CP subjects' tone 4 (the high-falling tone) are negative. There is no obvious difference between TDs' and CPs' mean slope of tone 4. Compared to other tones, TDs' and CPs' tone 4 seem to be the most similar. Tone 4 for CP children is also a rather easy tone to master.

Table 8. Mean slope of fundamental frequency (Fo)

	Tone 1	Tone 2		Tone 3		Tone 4
TDs	-0.191	-0.710	0.308	-0.631	0.348	-0.388
CPs	-0.162	-0.795	0.262	-0.534	0.212	-0.348

Discussion

CP children's pitch differs from that of TD children in mean duration and in mean standard deviation. It was found that CP children tend to spend more time and make more efforts in speech production due to the disorder of speech-motor control. In addition, the results of SD indicated that pitch production of CP children is more unstable than TD children's, reflecting the lack of speech-motor control. As for the mean slope of each tone, there is no obvious difference between TD and CP children.

In general, for both TD and CP children, tone 1 and tone 4 are easier to handle than the other tones. Therefore, the accuracy rate of both tone 1 and tone 4 is the highest among the four tones for both TD and CP children. The tone values of tone 1 and tone 4 are 55 and 51, respectively [22]. The procedure involved in the production of these two tones is relatively easy. In contrast, tone 3 for TD1, CP1 and CP2 is considered the most difficult tone to produce because the accuracy rate is the lowest among the four tones. Although the most difficult tone for TD2 seems to be tone 2, the accuracy rate of TD2's tone 3 is also low (72.73%; 8 words). The tone value of tone 3 is 214 [22], which is difficult for both TD and CP children.

4.3 Speech rate

Speech rate: the results of both SPM and ISPM of four subjects are presented in figure 1. Both SPM and ISPM of CP1 and CP2 are slower than TD1 and TD2.

(1) SPM: although CP1 performed the slowest SPM among the four, the rates of the four subjects were actually close. If we take further examination of CP2, his rate of SPM was 239 SPM, which could almost compete with the typically developing children, which were 254 SPM and 272 SPM respectively.

(2) ISPM: the differences between the group of CP children and the group of TD children are extended. While the rates of typically developing children remain almost the same, the rates of the group with cerebral palsy dropped much more slowly, especially in CP2. CP2 produced the rapid speech rate with a lower intelligibility.

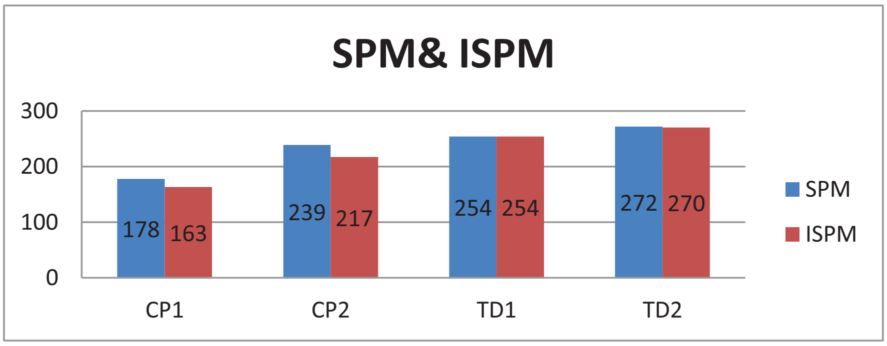

Figure 7. Speech rate in SPM (syllables per minute) and ISPM (intelligibles syllable per minute) of the four children

Speech intelligibility: in the part of speech intelligibility, the results in CP1 and CP2 were 76% and 63%, and in TD1 and TD2 were 98% and 92%, respectively. Compared with the speech rate, there is an obvious difference between CP children and TD children. Both CP1 and CP2 showed a lower intelligibility. Moreover, CP2's speech intelligibility was only 63%, which is the lowest of the four children. Compared to the group with cerebral palsy, TD1 and TD2 showed relatively high intelligibility, at 98% and 92% respectively. Furthermore, combined with the result of ISPM, although CP2 is the rapid speaker, his intelligibility has been affected by this rapidness and dropped more apparently than other three children. While CP1 produced the slower speech rate, his speech intelligibility was higher than CP2.

Discussion

Compared to that of typically developing children, the speech rate of the children with cerebral palsy group is slower. The findings in this paper that both SPM and ISPM of CP children are slower than TD children are consistent with the dysarthria literature ([3], [15], [16]). Moreover, group with cerebral palsy also demonstrated the lower speech intelligibility. Nevertheless, there were individual differences in CP children, especially in the case of CP2. CP2 showed similar speech rate as the TD group in SPM, which was much faster than CP1. This might be due to the different type of cerebral palsy. In this study, although CP1 is less severe than CP2 in cerebral palsy, CP1 is diagnosed with dyskinetic quadriplegia, and this type of cerebral palsy usually affects the speech production more obviously. Ingram and Barn [24] propose that the reason leading to dyskinetic dysarthria is generally because the motor control of the voluntary articulator in dyskinetic speakers has been aggravated by their involuntary movements, which leads to the disruption of the speech. Although there is disagreement in some of the latter findings [25], the influences of involuntary movements on the speech production of dyskinetic speakers merit investigation in future studies. As to CP2, his rapid speech may result from the repetition of the target items in picture naming. Through these repetitions, the duration of the repeated utterances became shorter. The repeated utterances take up 15% of the whole data, which might explain the fast speech rate of CP2. Furthermore, while examining the repeated utterances in CP2, it was found that even though children with cerebral palsy have some speech defects, they have the ability to adjust their speech rate at will. In the recording, when CP2 was mischievously playing with adults, he obviously slowed down or sped up the rate of the target utterances. This finding confirms previous literature that the dysarthric speakers can adjust their rate as needed, revealing that they are capable of planning speech production. From this rate flexibility in CP children, we can respond to the statement in LeDorze, Ouellet, and Ryalls [6] that the speech deficit in dysarthric speakers is a matter of performance, not of competence.

5. Summary and further studies

Due to the deficit of speech-motor control, children with cerebral palsy show substantial differences in speech production comparing with typically developing children. Regarding vowel space, CP children have scattered and non-uniform formant values of each vowel, which reflects that children with CP have a relative lack of ability to coordinate and control the movements of the tongue. Furthermore, the vowel space of CP children is smaller than that of TD children. This finding suggests that CP children have limited tongue mobility. As to pitch features of CP children, the mean duration of each tone in CP children is longer than that in TD children. This finding indicated that CP children tend to spend more time producing speech because of their impaired speech-motor control. In addition, pitch production in CP children tends to be more unstable than in TD children. With regard to speech rate, CP children have slower rate and reduced intelligibility than children who do not have CP. Moreover, a slower speech rate can improve the intelligibility of speech in children with CP.

The limitations in this preliminary study suggest directions for future research. First, the number of children included for analysis is limited. Future studies with more participants would yield more objective results, and the correlation of CP children's speech rate and their speech intelligibility could be verified. Second, the findings of this study were just based on the observation of 4-year-old children. Extended longitudinal observation can provide more complete data of the individual differences and the profile of the development in vowels, pitch patterns, speech rate, and other speech and language characteristics. Third, the background disturbance in the recording procedures compromised the quality of the recordings. The background noises made the measurement of vowel formant frequency and pitch values difficult.

Moreover, pitch production in CP children tends to be very inconsistent. Even within a monosyllabic utterance, CP children make constant changes in pitch. For instance, CP children pronounced “diàn” in “diànshì” (television) as “diàn én.” The pitch movement of this utterance looked abnormal and changing (Figure 8). The change of pitch within one monosyllabic utterance is very common in the data of CP children. Therefore, this also created some difficulties in the transcription and later in pitch analysis.

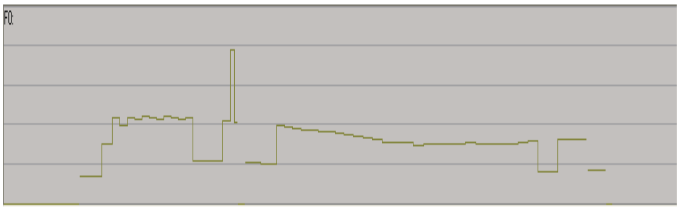

Figure 8. CP children’s bumpy pitch movement due to pitch changes within one syllable

Furthermore, speech productions of CP children tend to be fractured and discontinuous, just like grow pulse in [26]. It seems that CP children press the muscles too strongly in their larynx while speaking. Thus, the pitch movement shown in Figure 9 appears to be unstable, bumpy, and usually broken. The bumpy and unstable pitch movement makes the measurement of fundamental frequency very difficult.

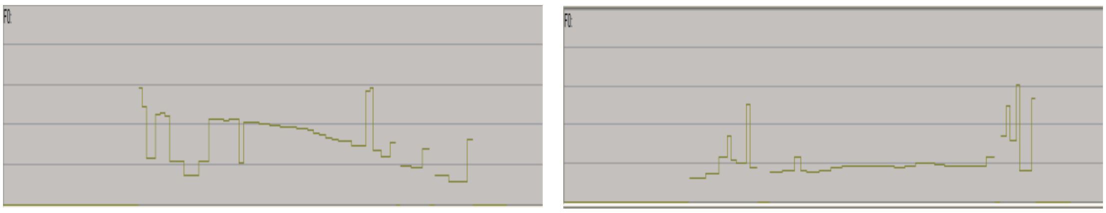

Figure 9. CP children’s bumpy pitch movement due to growl pulse

Last, in this study, the spontaneous speech data used in speech rate analysis, inevitably introduces variables. During the recording procedures, when the children became bored about the tasks they had to perform, they would produce faster and more unintelligible speech because of their impatience. This affected the study results. Accordingly, if we could minimize or eliminate these limitations in future or extended studies, the findings would be valuable for clinical speech-language intervention.

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