

Variability in vowel formant frequencies of children with cerebral palsy

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摘要

腦性麻痺為發展性運動神經障礙，而研究腦性麻痺語言特徵及其發展模式對於幼童早期語言發展的了解相當重要。母音在初期語言發展就已出現並且是了解語音聲學特性的關鍵。本研究旨在檢視五位腦性麻痺嚴重程度不同以及年齡層介於三到七歲的腦性麻痺幼童之母音共振峰頻率的差異。測量 F1 和 F2 的變化、母音空間分佈、母音空間面積。本研究結果顯示：1)三歲到七歲之間沒有發現 F2 明顯的下降；2) 母音橢圓形軌跡都有明顯的重疊；3)母音分佈沒有顯著的擴張，研究結果顯示這五位腦性麻痺小朋友有語言運動神經不協調和發音發展遲緩的情形。

關鍵字: 母音共振峰頻率、母音空間、腦性麻痺、學習國語幼童

Abstract

Cerebral palsy (CP) is a developmental motor disorder and the study of the speech characteristics and developmental speech patterns may provide valuable information on early speech development. Vowels appear early in speech development and they are central to the understanding of the acoustic properties of speech. Therefore, the current study aimed to examine the differences of vowel formant frequencies among five children with cerebral palsy in different severity ranging from ages 3 to 7. First and second vowel formants (F1 and F2) were measured to investigate: 1) the changes of the F1 and F2 values, 2) vowel space, and 3) the vowel space area in CP children of different ages and severity. The major findings are: 1) There was no obvious decline in F2 values from 3 to 7 years old, which indicated delayed speech development; 2) The overlapping ellipses of all vowel spaces illustrated unstable motor control in all the five children; and 3) The five CP children had centralized corner vowels and there was no expansion of vowel spaces at different ages. This indicated their limited motor control.

Keywords: vowel formant frequencies, vowel space, cerebral palsy, Mandarin-speaking

children

1. Introduction

Cerebral palsy is regarded as the most common cause of severe motor disability in children who are attributed to non-progressive disturbances that occurred in the developing infant brain [1]. Estimation from several different developed countries reported that 1.2-3.0 per 1000 children were diagnosed with cerebral palsy [2][3]. Vowels are central to the understanding of the acoustic properties for speech, and vowels appear early in speech development. Children achieve high degree of accuracy in producing vowels by the age of 36 months [4]. Therefore, the current study focused on vowel acoustical characteristics in five CP children of different ages.

2. Methodology

2.1. The participants

Five children with cerebral palsy participated in current study for investigating the differences of vowel formant in their speech production. General background information is described as follows.

Table 1. CP participants

	Gender	Age (in year; month, day)	Severity of Impairment	CFCS
CP1	Male	2;5,13	Moderate	Level II which distributed that the child is effective message sender/receiver with both unfamiliar and familiar communication partners but in a slow path
CP2	Male	2;9,16	Most Severe	Level IV which indicated that the child seldom effective message sender/receiver even with familiar partners
CP3	Male	3;11,6	Moderate	Between level IV (Self-Mobility with Limitations; May Use Powered Mobility) in between 4 th and 6 th birthday.
CP4	Male	4;11,16	Severe	Between level III and IV
CP5	Male	6;5,14	Severe	Between level IV (Self-Mobility with Limitations; May Use Powered Mobility) in between 4 th and 6 th birthday.

Five participants were observed individually by the Communication Function Classification System (CFCS) [5] as shown in Table 1. CP2 child, in 33 months, was diagnosed with hydrocephalus which caused severe brain damage and speech disorder.

2. 2 Data collection and analysis

A 50-minute recording from each child was analyzed, except for CP2. Due to very limited speech data from CP2, two recordings were used. The recordings were made in a quiet classroom with no noise disturbance (CP1) and the participant’s home (CP2, CP3, CP4, and CP5) with quiet environment and fewer disturbances. TASCAM DR-100 recorders with a SHURE wireless microphone system were used for data collection. The acoustic analysis was based on the 50-minute recordings which includes picture-naming task, and

spontaneous conversation between the observer, the child and the mother.

Every word in picture-naming task was transcribed. The first and the second formant frequencies (F1 and F2) of vowels were measured with time-frequency analysis, TF32 (Milenkovic, 2002) with reference to Linear Prediction Coefficient (LPC) and Fast Fourier Transformation (FFT). Vowel space was drawn to suggest the stability of vowels uttered by children with CP of different levels of severity. Furthermore, the corner vowel space areas were calculated with the vowels (/i, a, u/).

3. Results and discussion

3.1. Vowel formant frequencies

The value of F1 and F2 in vowels /i/, /e/, /u/, /a/, /ə/ and /o/ were analyzed for each child. The descriptive data for F1 and F2 values of all the 5 children is shown in Table 2. The values of F1 and F2 did not appear obvious differences in children with different ages. However, CP2 had very limited data on the vowel /u/ due to the severe brain damage. He could not successfully produce single word but limited sounds.

Table 2. Mean and standard deviation (in parentheses) of F1 and F2 values

Vowels	/i/		/e/		/u/		/a/		/ə/		/o/	
	F1	F2	F1	F2	F1	F2	F1	F2	F1	F2	F1	F2
CP1	559.5	3484.5	666.5	2713	594	1160	1059	2066	683	1589	817	1387
2;5,13	(78.9)	(375)	(216)	(704)	(118)	(281)	(258)	(414)	(174)	(366)	(178)	(237)
CP2	668	2627	779	2048	650	1297	1078	1935	681	1040	907	1422
2;9,16	(69)	(127)	(126)	(711)	(0)	(0)	(301)	(527)	(160)	(377)	(116)	(143)
CP3	610	3265	754	2709	676	1259	989	2222	814	2184	813	1594
3;11,6	(103)	(309)	(101)	(451)	(108)	(533)	(160)	(272)	(129)	(555)	(58)	(238)
CP4	479	3580	731	2888	555	1161	1008	1810	817	1766	666	1294
4;11,16	(67)	(183)	(166)	(494)	(103)	(251)	(163)	(283)	(115)	(209)	(136)	(243)
CP5	602	3065	770	2355	648	1252	765	1473	1118	1825	712	1790
6;5,14	(100)	(475)	(180)	(769)	(189)	(537)	(175)	(331)	(326)	(538)	(198)	(604)

Table 2 shows the mean and standard deviation of F1 and F2 of the main vowels produced by each child. Although there was no obvious difference among the severity groups as comparing the F1 and F2 values, CP4 (severe) tended to have lower F1 value in vowels /i/ and /o/, and CP2 (most severe) showed lower F2 value in vowels /i/, /e/ and /ə/.

Table 3. Mean and standard deviation (in parentheses) of F1 and F2 (sorted by severity)

Vowels	/i/		/e/		/u/		/a/		/ə/		/o/	
	F1	F2	F1	F2	F1	F2	F1	F2	F1	F2	F1	F2
Moderate	559.5	3484.5	666.5	2713	594	1160	1059	2066	683	1589	817	1387
CP1	(78.9)	(375)	(216)	(704)	(118)	(281)	(258)	(414)	(174)	(366)	(178)	(237)
Moderate	610	3265	754	2709	676	1259	989	2222	814	2184	813	1594
CP3	(103)	(309)	(101)	(451)	(108)	(533)	(160)	(272)	(129)	(555)	(58)	(238)
Mean	584	3374	710	2711	635	1209	1024	2144	748	1886	815	1490
Severe	668	2627	779	2048	650	1297	1078	1935	681	1040	907	1422
CP2	(69)	(127)	(126)	(711)			(301)	(527)	(160)	(377)	(116)	(143)
Severe	479	3580	731	2888	555	1161	1008	1810	817	1766	666	1294
CP4	(67)	(183)	(166)	(494)	(103)	(251)	(163)	(283)	(115)	(209)	(136)	(243)
Severe	602	3065	770	2355	648	1252	765	1473	1118	1825	712	1790
CP5	(100)	(475)	(180)	(769)	(189)	(537)	(175)	(331)	(326)	(538)	(198)	(604)
Mean	583	3090	760	2430	617	1236	950	1739	872	1543	761	1502

The frequency of occurrence of each vowel is described in Table 3 which indicated that vowel /i/ and /a/ appeared more frequently than other vowels since the age of 2. Data from

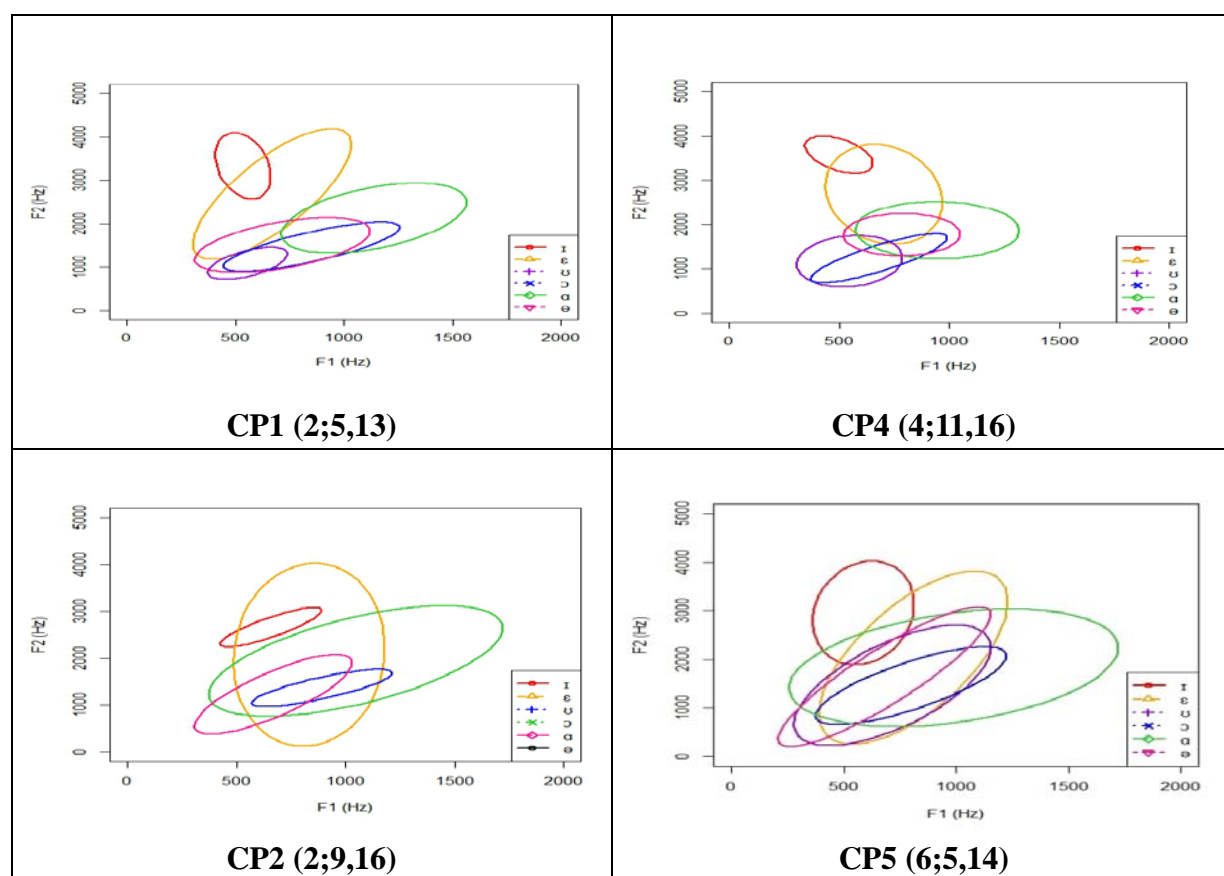
CP2 (severe) showed the opposite outcome in which vowels /i/ and /a/ appeared only 14% (6%+8%) and vowels /o/ and /ə/ appeared 77% (39%+38%). This may be due to the limited spontaneous speech production that the child produced.

Table 4. The frequency of occurrence of each vowel

	/i/	/ɛ/	/o/	/a/	/ɔ/	/ə/
CP1 (2;5,13)	25%	7%	16%	24%	14%	14%
CP2 (2;9,16)	6%	8%	1%	8%	39%	38%
CP3 (3;11,6)	23%	8%	12%	26%	15%	16%
CP4 (4;11,16)	24%	9%	7%	26%	21%	13%
CP5 (6;5,14)	22%	15%	16%	11%	25%	12%

3.2. Overall vowel space

The vowel space for all vowels is illustrated in the following figures. Figure 1 shows that the child at 29 months had not yet developed mature vowel production. The ellipses of vowel space were overlapping and centralized. CP2 had very unstable vowel production in which the ellipses are large. That is, the range of individual vowel was big. The vowel space for CP3 showed overlapping ellipses, which also indicated unstable vowel production. Even in the oldest child (6 years and 5 months of age) in this study, the production of vowels still appeared to be immature.



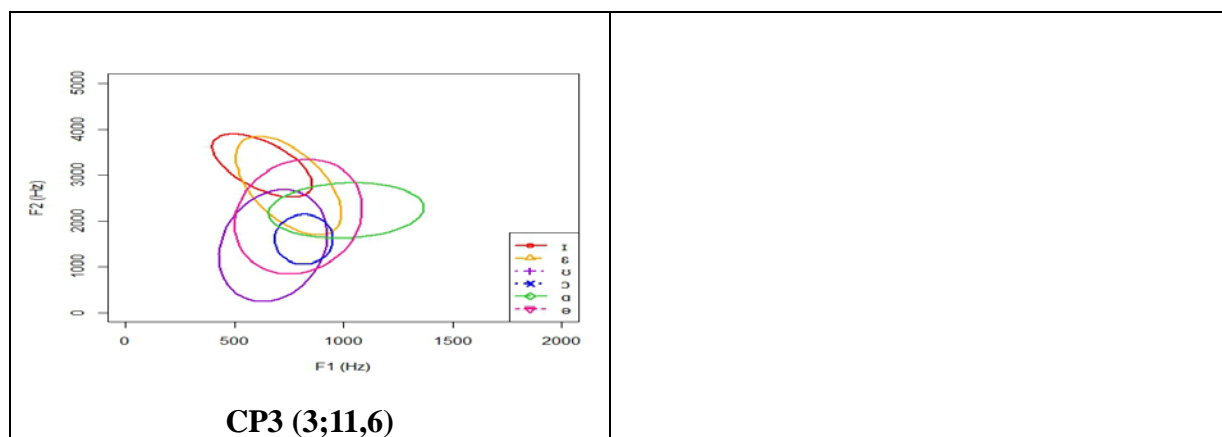


Figure 1. Vowel space of individual vowels

The vowel space above indicated the unstable vowel production by CP children in different ages. Table 5 displays the range of F1 and F2 values, and the data showed that CP1 had a very unstable F2 value in vowel /i/. CP2 had the smallest range of F2 in vowel /o/ even though CP2 was the most severe child with brain injury. The descriptive data also indicated that CP5 (77 months) had very unstable motor ability in which the range of F2 values of vowel /i/ was very large (from 940Hz to 3446Hz).

Table 5. Range of F1 and F2 values

CP		/i/		/ɛ/		/o/		/a/		/ɔ/		/ə/	
		F1	F2	F1	F2	F1	F2	F1	F2	F1	F2	F1	F2
CP1	Min	423	2281	439	1382	431	867	563	1551	521	1246	472	864
	2;5,13 Max	687	3788	905	3271	740	1375	1412	2715	1244	2240	953	2023
CP2	Min	563	2546	724	1206	650	1297	381	1030	730	1167	469	747
	2;9,16 Max	727	2843	1030	2835			1677	2851	1037	1508	959	2325
CP3	Min	437	2583	559	2119	563	1130	740	1767	728	1207	515	909
	3;11,6 Max	788	3832	943	3711	1000	3058	1278	2930	953	2103	1028	2885
CP4	Min	385	3230	384	1288	338	850	649	1423	468	812	597	1423
	4;11,16 Max	611	4008	876	3272	723	1767	1204	2542	946	1638	1030	2409
CP5	Min	335	940	571	890	555	1037	430	1031	477	951	334	642
	6;5,14 Max	816	3446	1166	2847	1169	2881	1426	3185	1122	2119	905	2329

3.3. Vowels area

The scatter plots in Figure 2 illustrate the distribution of the three corner vowels (i.e., /i/, /u/ and /a/) for each child. The blue dots represent the vowel /a/ and its range is scattered apart which indicates the instability in producing vowel /a/ for each child in this study. The lines were drawn to illustrate the changes of vowel space areas in different ages and severity. Previous studies indicated that children tend to have smaller vowel space in early age, and later expand a little when the children are older, then become more centralized. The broader vowel space at early stages corresponds to the increased variability of vowel formants which might be due to immature motor control [6][7]. After acquiring more mature motor control for vowel production, the decreased variability of vowel formants leads to the reduction of F1-F2 space at later stage. However, the current study did not discover obvious change of vowel space in different ages. In this current study, CP1 had larger corner vowel space than CP3 due to age difference. CP2, with severe dysarthria, tended to have very scattered corner vowels distribution due to the difficulty of motor control.

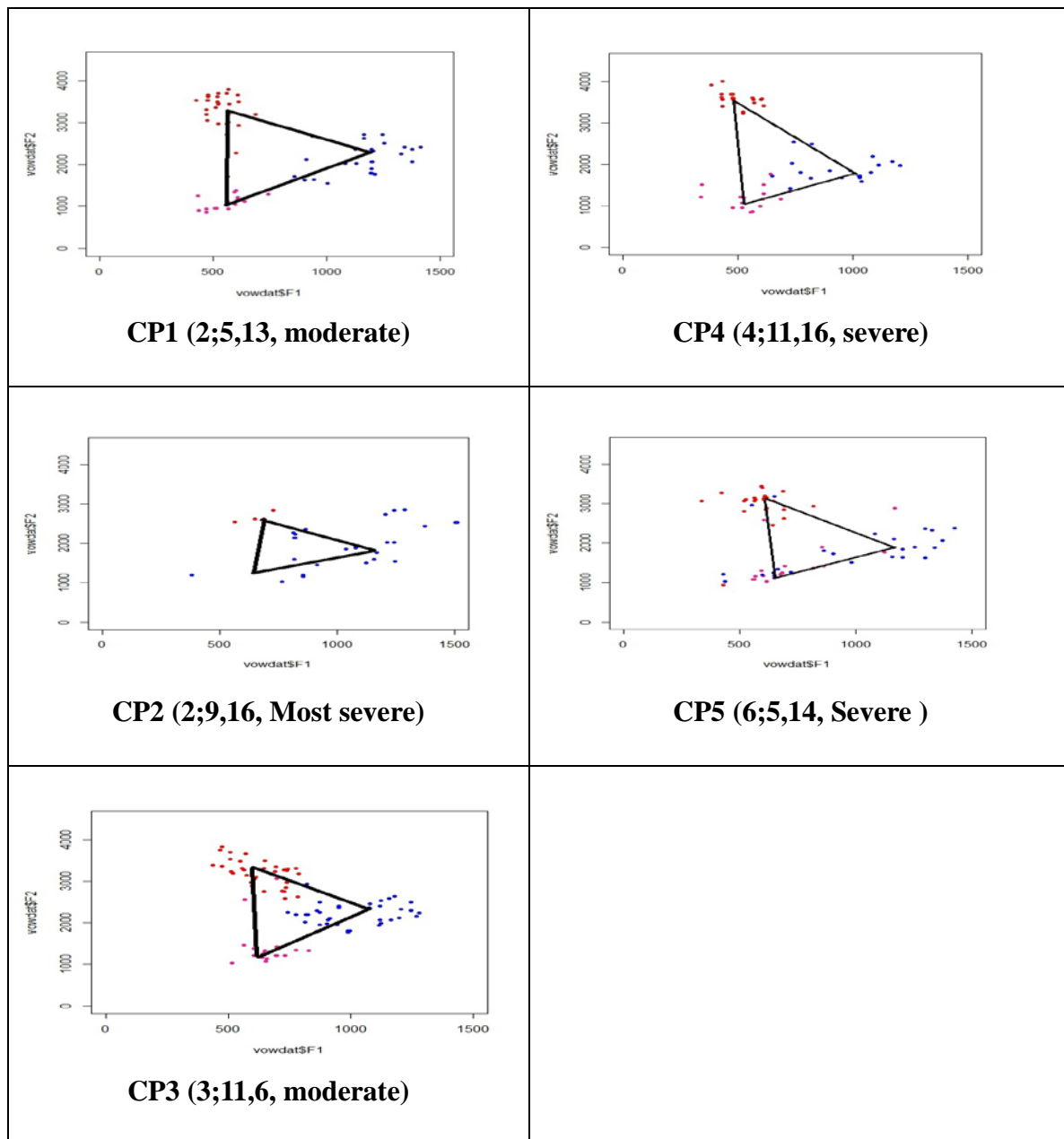


Figure 2. Overall vowel areas

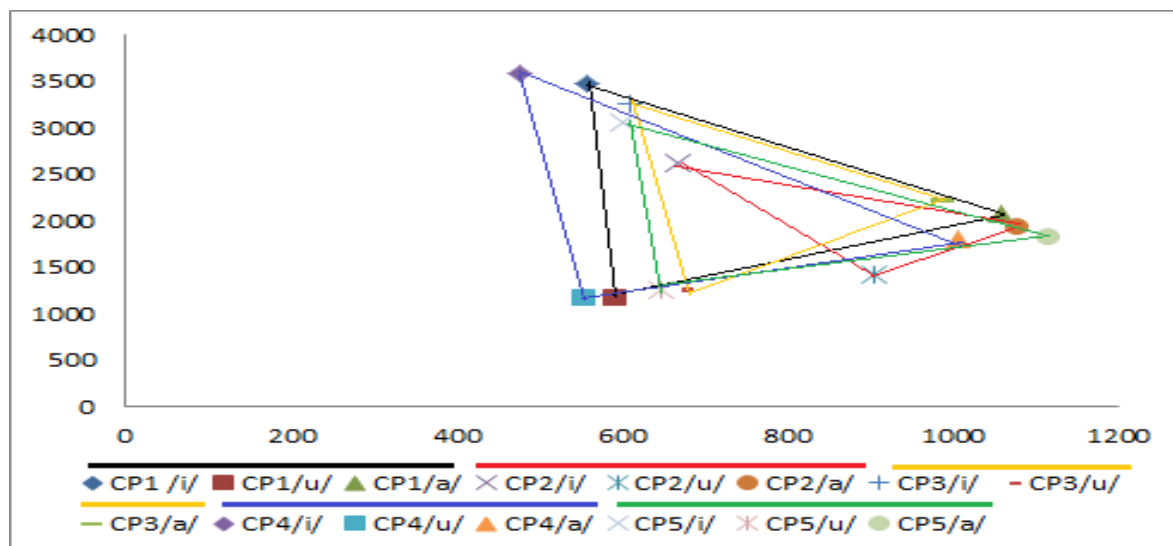


Figure 3. Vowel space for all participants. CP1 (black); CP2 (red); CP3 (yellow); CP4 (blue) and CP5 (green)

The vowel space with three corner vowels produced by the 5 children with different ages revealed no obvious trend of expansion or concentration of vowel spaces. However, the results indicated that, first, the major difference among participants appeared on F1 formant values, especially for vowel /i/ and /u/. Second, vowel /a/ appeared to be stable with no obvious changes by severity and age differences. Table 6 shows the corner vowel space area for each child. The results indicated that the vowel space tended to be larger in early ages, and then became smaller in older ages.

Table 6. Corner vowel space area (Hz²)

	CP1	CP2	CP3	CP4	CP5
Severity	Moderate	Severe	Moderate	Severe	Severe
Age	2;5,13	2;9,16	3;11,6	4;11,16	6;5,14
Area	556655 Hz ²	278985 Hz ²	345718 Hz ²	572422 Hz ²	439234 Hz ²

Previous study of children’s developmental changes in vowel production suggested that typically-developing children tended to have high F2 values in vowel /i/ at age 1 and decreased by process of age [8]. The result in current study showed that the F2 value of vowel /i/ in CP1 (29 months) had reached up to 3000 Hz. However, the F2 values of vowel /i/ did not decline with the process of age. CP4 appeared to have more than 3000 Hz of F2 values in vowel /i/ at age of 4. The data in the current study indicated unstable development in vowel production in terms of age difference in respect of F1 and F2 values. The findings are similar to the description in [9] which indicated that the abnormality in vowel development may provide valuable information in the understanding of early speech characteristics and speech development in CP.

Lee (2010) indicated that CP children with dysarthria have smaller vowel space areas than CP without dysarthria and typically-developing children. The five CP children participated in the current study were grouped as CP with dysarthria but in different severity (i.e., moderate and severe). However, the results in current study indicated that CP2 (most severe) had the smallest vowel space areas and CP4 (severe) had the largest vowel space area. In other words, the results did not show clear relation between the

severity, F1 and F2 values, vowel space, and vowel space area.

Due to the deficit of speech-motor control, children with cerebral palsy showed no obvious differences in speech production based on the comparison of vowel formant values in CP with different severities and ages. Regarding vowel space, all five CP children had scattered and non-uniform formant values, which reflected that children with CP had limited ability to coordinate and control tongue movement in vowel productions.

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