The 2016 Conference on Computational Linguistics and Speech Processing
ROCLING 2016, pp. 153-163

Speech Intelligibility and the Production of Fricative and Affricate among Mandarin-speaking Children with Cerebral Palsy

Chin-Ting Jimbo Liu
Department of Foreign Languages and Literature
National Cheng Kung University
K28011032@mail.ncku.edu.tw

Li-mei Chen
Department of Foreign Languages and Literature
National Cheng Kung University
leemay@mail.ncku.edu.tw

Yu-Ching Lin
Department of Physical Medicine and Rehabilitation, College of Medicine,
National Cheng Kung University
richelin@mail.ncku.edu.tw

Chia-Fang Anna Cheng
Department of Foreign Languages and Literature
National Cheng Kung University
anna17nut@gmail.com

Hui-chen Jennifer Chang
Department of Foreign Languages and Literature
National Cheng Kung University
garr07nni@gmail.com

Abstract

Literatures pertaining to English and Mandarin fricative/affricate productions by adults with cerebral palsy (CP) showed that acoustic measurements such as rise time contrast, initial burst rate contrast and friction noise duration contrast associated with fricative/affricate productions were highly correlated with overall speech intelligibility. However, the phonetic features of fricatives/affricates produced by Mandarin-learning children with CP were not fully explored. Therefore, this study targets on fricatives/affricates produced by ten Mandarin-learning CP children (Mean: 6;10, Range: 4;6 – 8;11) and ten Mandarin-learning typically developing children (Mean: 5;7, Range: 5;2 – 6;1). The current results from a speech repetition task showed that: 1) The fricative/affricate accurate rates and error patterns were similar between the two groups; 2) The differences between the two groups in terms of nine acoustic measurements (fricative/affricate rise time, initial burst rate, friction noise duration and their contrasts) and speech intelligibility were not statistically significant; 3) The rise time contrast was an effective contributor to overall speech intelligibility for CP children. Together with previous studies, the current study concluded that rise time contrast was the most significant contributor, among fricative/affricate measurements, to speech intelligibility across different age ranges.

Keywords: Children with cerebral palsy, Fricative, Affricate, Speech intelligibility, Mandarin Chinese.

1. Introduction

Improving cerebral palsy (CP) children's intelligibility is a key goal of speech therapy [1]. Therefore, identifying the contributing factors for speech intelligibility becomes of significant importance. There is a large body of literature available on probing into the acoustic features related to speech intelligibility. For instance, several studies focused on the relationship among the acoustic features of vowels and speech intelligibility in English [1], [2], [3] and in Chinese [4], [5]. The relationship between speech intelligibility and the lengths of vowels [2], [3], [6], [7] and the relationship between speech intelligibility and the speech rates [5], [6], [7] were also explored in details in the literature. However, the relationship between fricative/affricate productions and speech intelligibility received relatively little attention. Therefore, the purpose of this study is to investigate the acoustic features of fricative/affricate productions made by Mandarin-acquiring CP children. The understanding of the acoustical features of the segments produced by CP children bears significant clinical applications. For instance, language therapists might be able to adjust their program and course design based on the current results in order to cope with the need of CP children.

1.1 Acoustic features of fricatives and affricates among CP adults

Ansel and Kent [2] evaluated the relationship between specific acoustic features of speech and speech intelligibility of 16 English-speaking adults (Mean: 33 years old, Range: 21–41) with mixed CP. Among others, the results of their study showed that mean rise time and mean noise duration for fricatives were longer than affricates. Additionally, the fricative-affricate contrast, together with the front-back vowel contrast, high-low vowel contrast, and lax-tense vowel contrast, could account for 62.6% of the variance in intelligibility scores in the study.

In her dissertation, Jeng [8] measured the friction noise duration of the fricative/affricate productions from 30 CP adults with dysarthria (Mean: 19.83 years old, Range: 17-25). The results showed that there was little difference between the fricative noise duration and the affricate noise duration produced by CP speakers, although such difference was obvious among TD speakers. Statistical results indicated that the noise duration for the TD group was significantly longer than that for the CP group.

Liu et al. [4] investigated the relationship between seven acoustic features and speech intelligibility of 20 Mandarin-speaking young adults with CP (Mean: 18.5 years old, Range: 17-22). Although the results showed that there were no differences for noise duration contrast and initial burst rate contrast between CP and TD groups, initial burst rate was an effective predictor to speech intelligibility. More specifically, initial burst rate, together with the F2-F1 contrast and VOT contrast, were able to account for 74.84% of the variance in overall intelligibility. Additionally, the initial burst rate contrast was shown to be correlated to overall intelligibility among CP speakers, r =.06397, $p < .01$.

1.2 Interim summary and the present study

From a cross-linguistic perspective, onset rise time, initial burst rate and friction noise duration were reported to be highly correlated with intelligibility in English and/or Chinese. Furthermore, the contrasts between fricatives and affricates in each measurement might be potential factors contributing to the overall intelligibility. However, those studies focused on adults or young adults and the relationship between those acoustic measurements and speech intelligibility among Mandarin-acquiring CP children was still unclear. Therefore, this study intends to fill this gap by investigating the fricative/affricate productions from ten Mandarin-acquiring CP children (Mean: 6;10, Range: 4;6 – 8;11) and ten Mandarin-acquiring TD children (Mean: 5;7, Range: 5;2 – 6;1). The specific questions include: 1) What are the accuracy rates and error patterns of fricatives and affricates produced by CP and TD children; 2) If there are any differences among nine fricative/affricate-related acoustic measurements and speech intelligibility between CP and TD groups; and 3) How much variance of speech intelligibility could be accounted for by rise time contrast, initial burst rate contrast and friction noise duration contrast?

2. Methods

2.1 Participants

Ten Mandarin-acquiring CP children (Mean: 6;10, Range: 4;6 – 8;11) and ten Mandarin-acquiring TD children (Mean: 5;7, Range: 5;2 – 6;1) were included in the study. All the CP children were diagnosed by a physiatrist. A list of the CP/TD participants, CP classification and impairment severity, based on Gross Motor Function Classification System (GMFCS), are shown in **Table 1** (next leaf). Although each of the CP participants had different degrees of impairment severity, all of them were determined to have adequate intellectual competence and hearing ability to performed the required task in the experiment. All the children in the TD group were without any history of language-hearing related disorders, as reported by their parents.

2.2 Design and materials

TD participants were required to repeat 164 words, one by one, with all possible initial-rime combinations in Mandarin Chinese after they heard a sample production played out by speakers linked to a laptop computer. However, the time length required to perform the task was proved to be impossible for CP children due to their limited physical energy and concentration span. Therefore, the list of words was reduced to 39 for CP children. All the words with a fricative/affricate initial segment were further selected for further acoustic analyses. Specifically, the affricates in Mandarin Chinese included /tɕ, tɕ^{h}, ts, ts^{h}, tʂ, tʂ^{h}/ and the fricatives in Mandarin Chinese included /x, ɕ, s, ʂ, ʐ, f/.

2.3 Acoustic measurements

The nine acoustic measurements included in this study were fricative/affricate initial burst rate, fricative/affricate friction noise duration, fricative/affricate rise time, fricative-affricate initial burst rate contrast, fricative-affricate frication noise duration contrast and fricative-affricate rise time contrast. After the experimenters tagged the label with the criteria to be introduced below, a script was used to obtained the values of initial burst rate, frication noise duration and rise time. The contrasts were calculated by subtracting the fricative values from the affricate values. All the acoustic analyses and the scripts were done by using Praat [9] and only the correct productions of targets were included in the acoustic analyses.

Table 1. Characteristics of the ten CP and ten TD children

ID	Sex	Age (year#month;day)	Type	GMFCS Level
CP1	F	4#6;3	Spastic diplegic CP	III
CP2	F	8#9;14	Spastic diplegic CP, Dyslalia	II
CP3	M	5#4;16	Spastic diplegic CP	III
CP4	M	5#8;17	Spastic diplegic CP	III
CP5	M	6#3;18	Spastic diplegic CP	II
CP6	M	6#11;24	Spastic diplegic CP	IV
CP7	M	7#5;0	Rt spastic hemiplegic CP	II
CP8	M	7#6;8	Spastic diplegic CP	II
CP9	M	7#10;19	Mixed type (spastic & athetoid) CP	II
CP10	M	8#11;0	Lt spastic triplegic CP	III
TD1	M	5#11;1		
TD2	M	6#1;14		
TD3	M	5#8;3		
TD4	M	5#3;23		
TD5	F	5#7;26		
TD6	M	5#11;0		
TD7	M	5#9;11		
TD8	F	5#8;18		
TD9	F	5#2;14		
TD10	F	5#5;5		

2.3.1 Initial burst rate

A burst was expected to present in affricates as there was a stop preceding the fricative. The occurrence of a burst was determined by the waveform and the spectrogram collectively. There must be a burst in the waveform with the co-occurrence of a sharp spike corresponding to the onset of a burst of noise. The burst rates of fricatives and affricates were calculated by dividing the number of fricatives (or affricates) with a burst sign into the total number of the correct fricative (or affricate) productions.

2.3.2 Frication noise duration

The starting point of a fricative/an affricate was determined by locating a boundary on the left side and the right side of an intensity envelope. The script would automatically locate the point with the lowest intensity energy within the boundaries as the starting point of a fricative/an affricate. The ending point of a fricative/an affricate was determined by the location where the F1 of the following vowel occurred.

2.3.3 Rise time

Rise time is a measure of the time over which the amplitude envelope reaches its maximum [10]. Rise time was measured at the middle 80 % of fricatives/affricates in order to exclude the possible noise from the two boundaries. After the boundaries of fricative/affricate segments were identified (as described in 2.3.2), the script automatically calculated rise time.

2.4 Intelligibility

All the word productions, including those without fricative/affricate initials, were included in this part. All the productions of an individual child were transcribed with Chinese characters by three judges and each judge only judged the productions of an individual child in order to eliminate the potential familiarity effects of the materials. Therefore, a total of sixty (3 judges x 20 participants) judges with normal hearing and without any background in speech pathology were included in this study. Three correlational tests using Pearson Correlation showed that the three lists of scores were highly correlated (List 1 vs. List 2, $r = .973$, $n = 20$, $p = .000$; List 1 vs. List 3, $r = .953$, $n = 20$, $p = .000$; List 2 vs. List 3, $r = .916$, $n = 20$, $p = .000$). Therefore, the speech intelligibility score of each participant was the average of three scores from three individual judges.

3. Results

3.1 Accuracy rates and error patterns

The accuracy rates of fricative/affricate productions of TD and CP groups are shown in **Table 2**.

Table 2. Accuracy rates of fricative/affricate productions

	Affricates	**Fricatives**
CPs	69.5%	86.05%
TDs	68.00%	92.89%

A 2 (affricates vs. fricatives) x 2 (CPs vs. TDs) repeated measure ANOVA was performed to examine if there were any differences among the accuracy rates. The results indicated that fricative accuracy rates were significantly higher than affricate accuracy rates, $F(1, 18) = 8.986$, p = .008. No other comparisons/interactions showed significant effects. The results showed that TD and CP performed similarly in terms of the accuracy rates.

The error patterns are shown in **Table 3** and the percentage of each error type was displayed in **Figure 1**.

Table 3. Fricative / affricate error patterns among CP and TD speakers

Error Type	Instances	No. of Errors (%)
(De)retroflexion	/ts^{h}/ → [tʂ^{h}] /tʂ^{h}/ → [ts^{h}]	CP: 23 (57.5) TD: 31 (58.49)
Affricatization	/ɕ/ → [tɕ] /s/ → [ts]	CP: 10 (25) TD: 6 (11.32)
Fricatization	/ts/ → [s] /tɕ^{h}/ → [ɕ]	CP: 1 (2.5) TD: 4 (7.55)
(Un)aspiration	/tɕ/ → [tɕ^{h}] /ts^{h}/ → [ts]	CP: 3 (7.5) TD: 2 (3.77)
Fronting	/x/ → [f] /tɕ/ → [ts]	CP: 1 (2.5) TD: 5 (9.43)
Backing	/f/ → [s] /ɕ/ → [x]	CP: 1 (2.5) TD: 2 (3.77)
Others	/ts/ → ∅ /x/ → [k^{h}]	CP: 1 (2.5) TD: 3 (5.66)

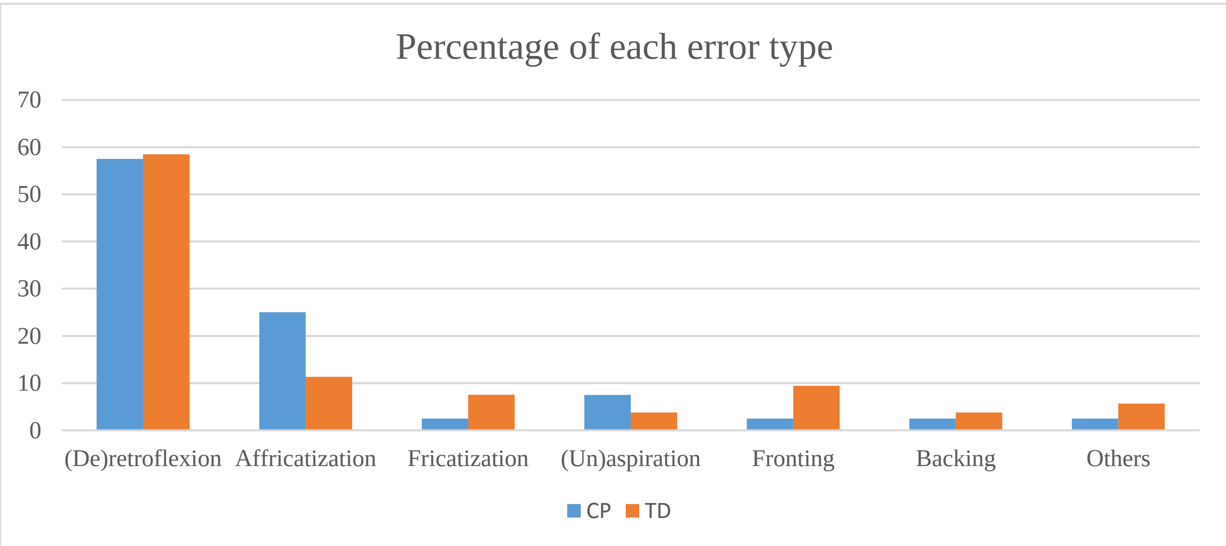

Figure 1. Percentage of each error type between CP and TD groups

As retroflex productions in Taiwan Mandarin are less retroflexed than Beijing Mandarin and are often dropped, it was not surprising that the trend was observed among child speakers. Affricatization was the second highest error type in both groups, although the percentage appeared to be higher among CP speakers. While TD children tended to have a higher error rates in fricatization and fronting, these trends were not observed among CP children. In short, the general patterns were similar, although there were some variations within the two groups.

3.2 Comparisons of nine acoustic measurements and intelligibility

A summary of the comparisons of nine acoustic measurements and intelligibility between CP and TD groups is shown in **Table 4**. The results of ten independent-samples t-tests indicated that none of the comparisons were statistically significant, showing that the acoustic features and intelligibility of fricative/affricate productions by TD and CP children were similar.

Table 4. Summary of the comparisons

Measurement (unit)	**CP (n = 10)** Mean (SD)	**TD (n = 10)** Mean (SD)	**t**
Intelligibility (%)	71.79 (18.74)	81.19 (10.75)	-1.376
Fricative friction noise duration (msec.)	298.12 (557.56)	276.33 (413.01)	.099
Affricate friction noise duration (msec.)	303.03 (607.79)	239.29 (267.58)	.304
Noise duration contrast (msec.)	4.91 (65.47)	-37.04 (147.14)	.824
Fricative burst rate (%)	2.68 (5.66)	2.87 (2.82)	-.099
Affricate burst rate (%)	60.43 (35.54)	68.66 (22.59)	-.618
Burst rate contrast (%)	57.74 (33.95)	65.78 (21.57)	-.613
Fricative rise time (msec.)	124.11 (218.12)	86.95 (72.53)	.511
Affricate rise time (msec.)	89.53 (134.29)	74.87 (36.69)	.333
Rise time contrast (msec.)	-34.586 (86.55)	-12.08 (39.59)	-.748

3.3 Multiple regression

A multiple regression was performed to examine the relative contribution of friction noise duration contrast, rise time contrast and burst rate contrast to CP's speech intelligibility. A summary table can be found in **Table 5** (next leaf). The results showed that these variables significantly predicted CP's speech intelligibility, $F(3, 6) = 10.51$, $p = .008$, $R^2 = .840$, adjusted $R^2 = .760$. Furthermore, rise time contrast was a significant contributor, $p = .014$. A unit increase in initial rise time contrast would result in .213 unit increase in CP children's speech intelligibility.

Table 5. Summary of the multiple regression

Variables	B	S.E. B	*β*	*p*
Constant	85.303	8.117		.000
Frication duration contrast	-.021	0.83	-.067	.811
Initial burst rate contrast	-.064	.110	-.116	.583
Rise time contrast	.213	.062	.922	.014

4. Discussion

In this study, we intended to examine Mandarin-acquiring CP children's productions of fricatives and affricates by comparing accuracy rates, error patterns and nine acoustic measurements of fricatives/affricates with TD controls. The relationship between speech intelligibility and three sets of fricative-affricate acoustic measurement contrast were investigated, too. The results showed that: 1) The fricative/affricate accurate rates and error patterns were similar between the two groups; 2) The differences between the two groups in terms of nine acoustical measurements (fricative/affricate rise time, initial burst rate, friction noise duration and their contrasts) and speech intelligibility were not statistically significant; 3) The rise time contrast was an effective contributor to overall speech intelligibility for CP children.

The current findings replicate several studies focusing on CP/TD adults in the literature. First, the Mandarin-speaking CP young adults in Liu et al.'s [4] study did not perform differently with the TD controls in terms of the burst rate contrast and friction noise duration contrast. The current study focusing on Mandarin-acquiring CP and TD children had the same finding. That is, there were no obvious differences in burst rate contrast and friction noise duration contrast among CP and TD children. Second, the current study agreed with the finding from Ansel and Kent [2] in that fricative-affricate contrast might be an influential factor affecting speech intelligibility. More specifically, the current study showed that rise time contrast, among the three sets of fricative-affricate contrast employed in this study, was the most influential factor impacting CP children's speech intelligibility. In short, together with previous studies, the current study demonstrated that, at least for 6-year-olds and young adults, burst rate contrast and frication noise duration contrast were not an effective measurement in distinguishing the speech characters of fricatives and affricates produced by CP and TD individuals. Additionally, rise time contrast might be the most influential factor, among other fricative/affricate-related measurements, affecting the speech intelligibility of CP and TD individuals.

Although some of the results replicate the findings in studies whose participants were CP adults, one difference still remains. In Jeng's [8] study, the friction noise duration among TD speakers were significantly longer than the for the CP group. Also, the author observed an obvious difference between the fricative noise duration and the affricate noise duration produced by TD speakers but not among CP speakers. However, in the current study, the results of t-tests showed that there were no differences of fricative noise duration, affricate noise duration and fricative-affricate noise duration contrast between TD and CP groups. As one obvious difference between Jeng's [8] study and the current study was the age of the participants, we attributed the different findings to the age effect. More specifically, it might be possible that some finer-grained acoustic features, such as friction noise duration, were still developing among TD groups; therefore, the friction noise duration differences among TD and CP children were less obvious.

5. Conclusion and final remarks

Based on the current experimental results, we conclude that, for fricative and affricate productions among TD and CP children, a) the accurate rates and error patterns are similar and b) rise time contrast can be an effective contributor overall speech intelligibility for CP children.

To our best knowledge, this is one of the very first studies that explored CP children's fricative/affricate productions by using acoustic measurements. We hope that: 1) With more studies from a variety of languages, the unique (and possibly universal) contributor of fricative/affricate productions to speech intelligibility can be identified; 2) With longitudinal studies, the changes of different indices in distinguishing TD and CP speakers and the influential contributor to speech intelligibility across different ages can be identified. We left those issues as a direction for future studies.

Acknowledgements

This investigation was supported through funds from Ministry of Science and Technology in Taiwan (MOST 104-2410-H-006-061). We thank all of the children, parents and teachers for their participation.

References

[1] K. Allison and K. Hustad, "Impact of sentence length and phonetic complexity on intelligibility of 5-year-old children with cerebral palsy", *International Journal of Speech-Language Pathology*, vol. 16, no. 4, pp. 396-407, 2014.

[2] B. Ansel and R. Kent, "Acoustic-Phonetic Contrasts and Intelligibility in the Dysarthria Associated With Mixed Cerebral Palsy", Journal of Speech Language and Hearing Research, vol. 35, no. 2, p. 296, 1992.

[3] J. Lee, K. Hustad and G. Weismer, "Predicting Speech Intelligibility With a Multiple Speech Subsystems Approach in Children With Cerebral Palsy", *J Speech Lang Hear Res*, vol. 57, no. 5, p. 1666, 2014.

[4] Huei-Mei Liu, Chin-Hsing Tseng, Fen, "Perceptual and acoustic analysis of speech intelligibility in Mandarin-speaking young adults with cerebral palsy", *Clinical Linguistics & Phonetics*, vol. 14, no. 6, pp. 447-464, 2000.

[5] C. Yang and H. Liu, "The impact of a speaking-rate training program on speech intelligibility in students with spastic cerebral palsy", *Bulletin of Special Education*, vol. 32, no. 4, pp. 65-83, 2007.

[6] K. Hustad and J. Lee, "Changes in Speech Production Associated With Alphabet Supplementation", *J Speech Lang Hear Res*, vol. 51, no. 6, p. 1438, 2008.

[7] E. Lin, C. Chen and C. Lee, "Speech motor deficits in cerebral palsied children: An acoustic-perceptual approach", The 5th Asia Pacific Conference on Speech, Language and Hearing, Brisbane, 2007.

[8] J. Jeng, "Intelligibility and acoustic characteristics of the dysarthria in Mandarin speakers with cerebral palsy", Dissertation, University of Wisconsin—Madison, 2000.

[9] P. Boersma, "Praat, a system for doing phonetics by computer", *Glot International*, vol. 5, no. 9/10, pp. 341-345, 2002.

[10] R. Kent and C. Read, *The acoustic analysis of speech*, 2nd ed. NY: Singular, 2002.