

Consonant initial articulation in dysarthric speech: A case of cerebral palsy

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ABSTRACT

This study examines the consonant initial production in dysarthric speech of an adult with cerebral palsy (CP), based on naturalistic speech data from accessible performances. Perceptual and acoustic analyses of 21 Mandarin initials revealed an overall error rate of 11.51%, indicating moderate dysarthria. Errors were more frequent in consonants requiring posterior articulation or complex lingual gestures (e.g., /x/, /l/, /f/) than in anterior or simple consonants (e.g., bilabials and alveolars). Substitutions accounted for 90.91% of errors, primarily reflecting place and manner changes attributable to motor control deficits, while distortions constituted 9.09% of errors. No omissions were observed. The findings underscore the influence of articulatory complexity and spasticity on consonant production and offer both theoretical and clinical insights into speech rehabilitation strategies for adults with dysarthria.

KEYWORDS

consonant initial articulation; dysarthric speech; cerebral palsy

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1. Introduction

Consonant production is central to speech intelligibility, and motor speech disorders can impair the accurate articulation of consonant initials. In Mandarin, consonant initials carry important phonemic distinctions, yet research on consonant initial articulation in adults with cerebral palsy (CP) remains limited. Drawing on naturalistic speech data, this study describes the consonant initial articulation of Xiaojia, a 31-year-old adult with spastic cerebral palsy and professional stand-up comedy experience, and examines the patterns and mechanisms underlying his production errors.

1.1. Research Questions

This study aims to describe the characteristics of consonant initial articulation of Xiaojia, an adult with spastic dysarthria due to cerebral palsy, using his public talk show recordings and Praat acoustic analysis. Research questions include: 1) What consonant initial production errors appear in Xiaojia's speech? 2) How does Xiaojia produce these consonant initials? 3) Why does Xiaojia commit these errors?

1.2. Research Significance

This study has theoretical, practical, and social significance. It adds to the existing data on how adults with spastic cerebral palsy articulate consonants, by looking at their speech in real communicative situations, and gives case-based evidence for studying articulation problems specific to adults. Moreover, this case helps us better understand the adaptive ways of speaking that work for speech-related jobs. It also provides useful ideas to support adults with cerebral palsy in joining interpersonal work. Last but not least, the study reveals that people can communicate well even if their articulation is not standard, which might encourage more functional views on how people with articulation problems can be understood by others.

2. Literature Review

Previous research on consonant production in individuals with cerebral palsy (CP)-related dysarthric speech has mainly focused on children's pronunciation and speech features. Chen et al. (2007) compared Mandarin-speaking children with CP and typically developing (TD) children by analyzing their speech subsystem (articulatory-phonetic, phonatory, and

prosodic). Similarly, Liu et al. (2020) also conducted a comparative analysis between CP and TD children but focused on the fricative production of 5-year-old young patients. Nordberg et al. (2014) noted consistent associations between consonant errors and overall speech impairment in school-aged children with CP.

In contrast, adult-focused research remains less detailed. Schoelderle et al. (2016) described the clinical presentation and communication impacts of dysarthria in adults with CP but lacked analysis of consonant-specific patterns. Although Liu and Chen (2021) used consonantal landmarks to predict dysarthria in English-speaking adults with CP, equivalent research on Mandarin-speaking adults is scarce. In addition, most studies rely on controlled speech tasks with limited exploration of consonant production in naturalistic contexts.

Other studies pay attention to speech intelligibility in dysarthric speech. For example, Kim et al. (2010) found that consonant phonemes with high articulatory complexity were most often misarticulated and proposed a two-part model of consonant articulation errors. Building on this work, Kim and Gurevich (2023) identified positional asymmetries in consonant production and their direct correlation with speech intelligibility. They argued that initial consonants might have resistance to production errors, necessitating more research on non-initial consonants. However, this view does not seem to adjust well to the Chinese language environment. Wang and others' (2010) research shows that children with cerebral palsy (CP) have relatively severe problems with the pronunciation of consonant initials, and the accuracy of these initials also affects speech intelligibility.

The subject of the current study is Xiaojia, a 31-year-old stand-up comedian with spastic cerebral palsy. As a native Mandarin speaker with five years of professional performance experience, Xiaojia presents a unique case study opportunity. Analysis of his public performance recordings reveals articulation patterns that, while demonstrating non-standard speech characteristics, remain intelligible to audiences. His speech samples embody both pathological articulatory features and professionally developed adaptive strategies. Such characteristics make this case particularly valuable for examining the functional communication mechanisms employed by adults with articulation disorders in professional contexts, and may inform therapeutic approaches for speech adaptation in similar populations with comparable conditions.

3. Methodology

3.1. Data Source

The research subject was Xiaojia, an adult with spastic cerebral palsy, whose native language is Mandarin with no hearing or intellectual impairments, and who has regular public talk show performance experience. The data in this research were extracted from 4 complete public talk show videos (total duration: 40 minutes) posted on a mainstream video platform (bilibili.com). The audio clips used in this essay are accessible at https://pan.baidu.com/s/1wwAsOT4i9NEb1YIja74S_w?pwd=2025 (password: 2025). We transcribed the audio-verbal content, annotated the positions of 21 Mandarin consonant initials, and excluded segments with strong background noise (e.g., excessive audience applause). Valid audio clips containing target consonants were extracted as WAV files for subsequent analysis.

3.2. Data Analysis

This study adopted a mixed-methods approach combining perceptual error classification and acoustic analysis via Praat (Version 6.4.34) to systematically examine Xiaojia's consonant production.

First, perceptual error classification was conducted with reference to the dysarthria examination scale developed by a Chinese rehabilitation research center. Two rounds of annotation were completed by the researcher at a 1-week interval to ensure reliability: the first round involved transcribing erroneous consonants from audio clips and matching them to standard forms (e.g., identifying /x/ as a substitution for /f/ in “发”); the second round re-annotated 20% of randomly selected clips. Intra-rater consistency was verified using Cohen's Kappa coefficient ($Kappa = 0.86$), indicating high reliability. Errors were categorized into three types: substitution (replacing one consonant with another identifiable one), distortion (unclear productions inferable only from context), and omission (complete absence of initial consonants).

Second, acoustic parameter extraction via Praat targeted core features of different consonant manners: (1) For stops (/p/, /p^h/, /t/, /t^h/, /k/, /k^h/), the closure duration (time from articulatory contact to release) and Voice Onset Time (VOT, interval between release and vocal fold vibration) were measured using waveform and spectrogram annotations; (2) For fricatives (/f/, /x/, /ɸ/, /s/, /ʃ/), friction duration (length of turbulent noise) and spectral centroid (frequency of maximum energy, indicating friction intensity) were extracted; (3) For nasals (/m/, /n/) and laterals (/l/), Formant 1 (F1) and Formant 2 (F2) were measured at the midpoint of consonant production to capture resonance characteristics (e.g., nasalization for /n/ vs. lateral airflow for /l/).

Finally, statistical analysis was performed using Microsoft Excel 2021. Error rates were calculated as (Number of errors for a consonant / Total occurrences of that consonant) $\times$ 100%, with grouping by the place (bilabial, labiodental, etc.) and manner (stop, fricative, etc.) of articulation. Acoustic parameters of erroneous productions (e.g., VOT of /p/ vs. /p^h/ substitutions) were further analyzed to quantify acoustic deviations, providing objective evidence for perceptual error patterns.

4. Results and Discussion

4.1. Overview of Consonant Articulation Errors

Based on the comparison between Xiaojia's erroneous consonant productions and the standard consonant statistics from the script, the overall characteristics of his consonant errors can be clearly identified. First, regarding error frequency and coverage, 52 pairs of comparative text segments were extracted, and after excluding vowel errors and cases with consistent initial consonants, 48 valid consonant errors were identified. These errors involved 13 out of the 21 Mandarin initial consonants (i.e., /p/, /m/, /f/, /t/, /t^h/, /n/, /l/, /x/, /tɕ/, /tɕ^h/, /tʂ/, /ts/, /z/), while no errors were found in /p^h/, /k/, /k^h/, /ç/, /tʂ^h/, /ʃ/, /tʂ^h/, /s/. This indicates a wide but selective distribution of errors.

Table 1 shows the frequency of consonant initial production errors. The consonant initial /f/ had the highest error frequency, occurring 14 times (29.17%). In contrast, several consonant initials, including /m/, /x/, /tɕ^h/, and /z/, had the lowest error frequency, each occurring only once (2.08% for each).

Erroneous Consonant Initials	Example	Frequency	Proportion (%)	Total Errors
/p/	病	2	4.17%	48
/m/	慢	1	2.08%	48
/f/	发, 法, 反	14	29.17%	48
/t/	得, 朵	2	4.17%	48
/t ^h /	台, 天, 统	4	8.33%	48
/n/	脑, 能, 年	4	8.33%	48
/l/	来, 乐, 了	9	18.75%	48
/x/	活	1	2.08%	48
/tɕ/	佳, 就, 居	3	6.25%	48
/tɕ ^h /	起	1	2.08%	48
/tʂ/	这种, 知, 种	4	8.33%	48
/ts/	在, 早	2	4.17%	48
/z/	人	1	2.08%	48

Table 1. Frequency of Consonant Initial Production Errors

4.2. Error Rates by Place of Articulation

Mandarin initial consonants are categorized into 7 groups by place of articulation. Below is the analysis of error rates and characteristics for each group, based on error frequency and total occurrences:

Bilabials (/p/, /p^h/, /m/): With 60 total occurrences and 3 errors (e.g., mistaking /p^h/ for /p/ in “病”, and /w/ for /m/ in “慢”), the error rate was 5%. Errors included substitutions within bilabials (e.g., aspirated /p^h/ $\rightarrow$ unaspirated /p/) and between semivowels and bilabials (e.g., /w/ $\rightarrow$ /m/). Since bilabial articulation only requires simple closure and release movements, spasticity has minimal impact on lip muscle control, resulting in the lowest error rate.

Based on the perceptual impression of Xiaojia's mistaking /p^h/ for /p/ in “病”, the acoustic evidence was re-examined. Contrary to the initial hypothesis that unaspirated /p/ was substituted for aspirated /p^h/, the spectrogram and waveform suggest a different pattern. The display reveals a relatively clear burst upon release, followed by a short but visible period of voiceless aspiration noise before the onset of the vowel. This is evidenced by diffuse energy in the mid-frequency region (around 1–2 kHz) and a slight delay in the start of voicing. The Voice Onset Time (VOT), though not excessively long, is longer than that typical for an unaspirated stop in Mandarin, measuring approximately 30–40 ms. This supports the perceptual observation of an aspirated production. Thus, rather than de-aspiration, the error may involve hyper-aspiration or an exaggerated release, possibly due to incoordination between laryngeal and supralaryngeal mechanisms, resulting in an unexpected aspirated quality.

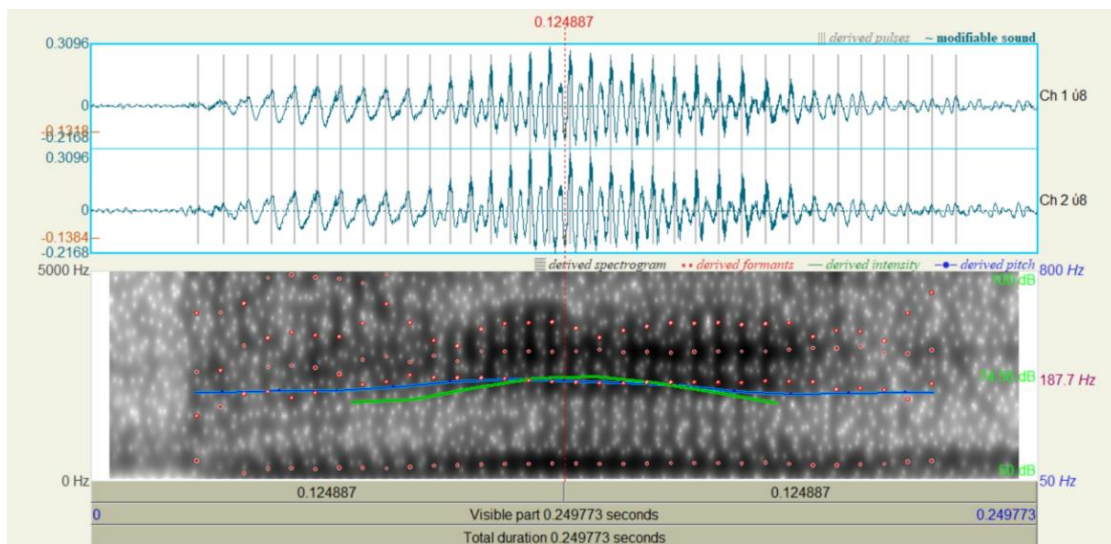


Image 1. Xiaojia's pronunciation of “病”

Labiodentals (/f/): With 30 total occurrences and 8 errors (e.g., mistaking /x/ for /f/ in “发”, /x/ for /f/ in “佛”), the error rate was 26.67%. All errors involved the velar /x/ substituting for /f/. This is because /f/ requires light contact between the lower lip and upper teeth, while Xiaojia's velar muscle spasticity made the velar elevation difficult. He thus compensated by using /f/, which is easier to control via labiodental contact—a form of posterior-to-anterior substitution.

The image below shows that the target consonant is the labiodental fricative /f/, which should show continuous high-frequency friction noise. Instead, the spectrogram reveals a concentration of energy in the mid-to-low frequencies (around 1–2 kHz), characteristic of a velar fricative /x/. The absence of strong high-frequency noise (above 4 kHz) indicates lack of labiodental constriction. The waveform shows aperiodic noise with a lower spectral centroid than expected for /f/, confirming the substitution error. This reflects Xiaojia's difficulty with anterior articulatory precision and compensatory use of posterior articulation.

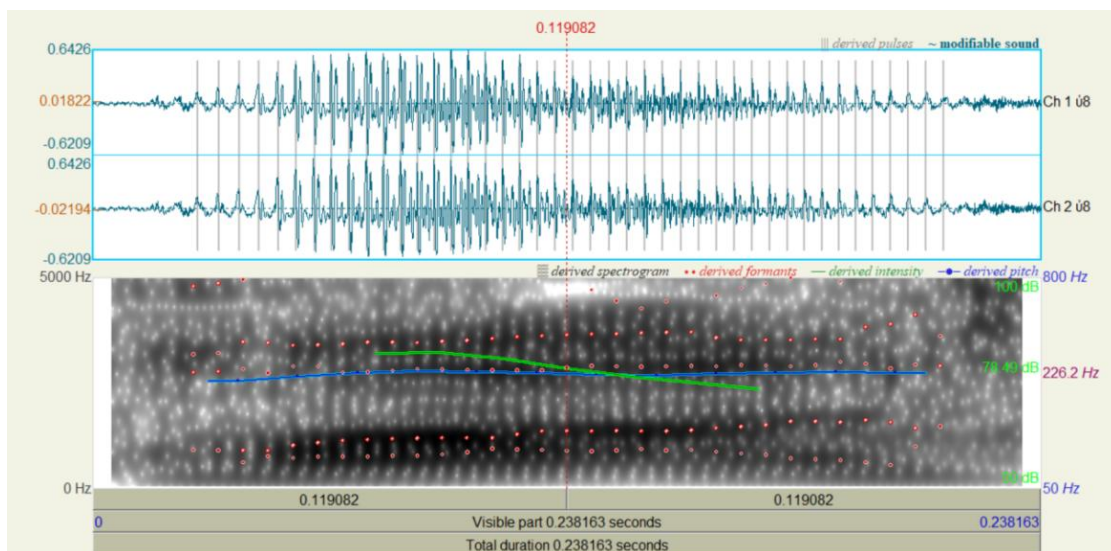


Image 2. Xiaojia's pronunciation of “发”

Alveolars (/ts/, /tsʰ/, /s/): With 50 total occurrences and 2 errors (e.g., mistaking /ts/ for /tʂ/ in “知”, and a zero initial for /ts/ in “在”), the error rate was 4%. Errors included cross-substitutions between alveolars and retroflexes (e.g., /ts/ → /tʂ/) and substitutions of zero initials for /ts/. Since alveolars only require the tongue tip to lightly touch the alveolar ridge (a short movement path), spasticity has minimal impact on anterior tongue muscle control, leading to an error rate second only to bilabials.

When Xiaojia produces the word “知”, the target consonant initial is the retroflex affricate /tʂ/, which acoustically manifests as a brief silence period followed by mid-frequency frication. The presented visualization, however, shows no clear closure interval and reveals fricative noise with spectral emphasis in higher frequencies than typical for retroflexes, resembling an alveolar articulation such as /ts/ or /s/. The absence of lower-frequency resonance and the shortened

duration of frication suggest articulatory undershooting, supporting the observed substitution error between retroflex and alveolar consonants.

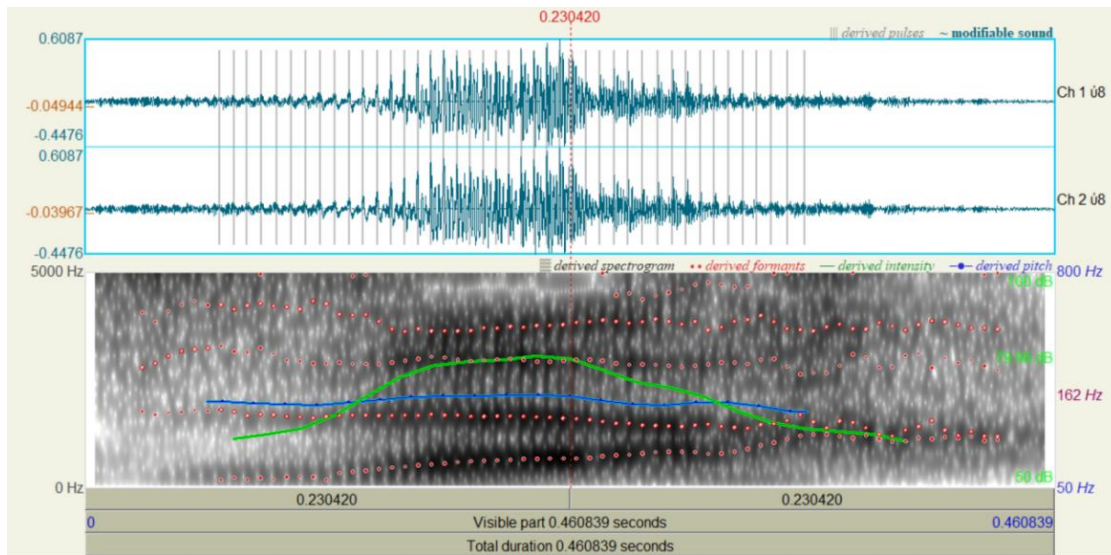


Image 3. Xiaojia's pronunciation of "知"

Apical Alveolars (/t/, /tʰ/, /n/, /l/): With 95 total occurrences and 14 errors (e.g., mistaking /y/ for /t/ in "统", /n/ for /l/ in "恋"), the error rate was 14.74%. Errors focused on nasal-lateral substitutions within apical alveolars (e.g., /n/ ↔ /l/, 5 cases) and substitutions of other consonants for apical alveolars (e.g., /s/ → /l/, 9 cases). For /n/ and /l/, sustained tongue-tip contact with the alveolar ridge and airflow control (nasal vs. lateral) are required; spasticity impairs the stability of tongue-tip contact and airflow coordination, resulting in a higher error rate than the previous two groups.

The following image corresponds to the production of "统", beginning with the alveolar aspirated stop /tʰ/. Acoustic measurements reveal a very short voice onset time (VOT) and a weakly defined burst in the spectrogram. The transition into the following vowel appears blurred, with formant movements lacking clear definition. The waveform shows a low-amplitude release burst and premature onset of periodic vibration. These features signal a deaspiration error, likely perceived as an unaspirated stop, resulting from compromised intraoral pressure or coordination between glottal and supralaryngeal gestures.

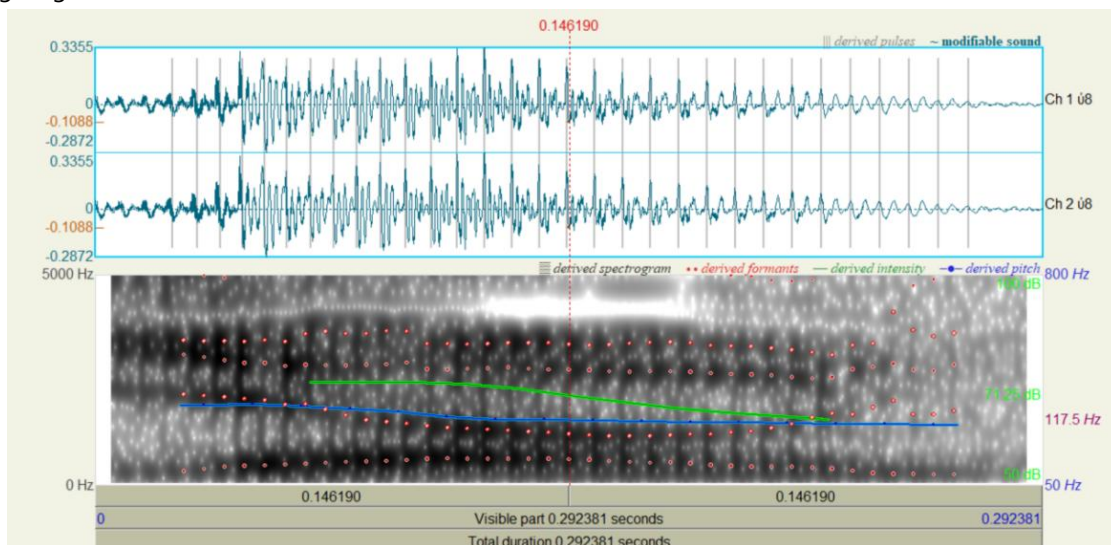


Image 4. Xiaojia's pronunciation of "统"

Retroflexes (/ʈʂ/, /ʈʂʰ/, /ʂ/, /ʐ/): With 53 total occurrences and 5 errors (e.g., mistaking a zero initial for /ʈʂ/ in "种", /x/ for /ʂ/ in "生"), the error rate was 9.43%. Errors primarily involved substitutions of other consonants for retroflexes (e.g., /x/ → /ʂ/, zero initial → /ʈʂ/). Retroflexes require the tongue tip to curl back and touch the hard palate; Xiaojia's lingual posterior spasticity limited this movement, forcing him to substitute with easier-to-control consonants like the palatal /tʃ/ or velar /x/.

The spectrogram here depicts the utterance of “生”, where the initial consonant should be the retroflex fricative /ʂ/. Instead, the acoustic output shows strongest resonance below 2 kHz, accompanied by a noisier and more diffuse spectrum, aligning with the properties of the velar fricative /x/. The waveform exhibits sustained low-frequency turbulence without the intense high-frequency noise expected for /ʂ/. This confirms a substitution error influenced by tongue retraction and reduced anterior articulatory control.

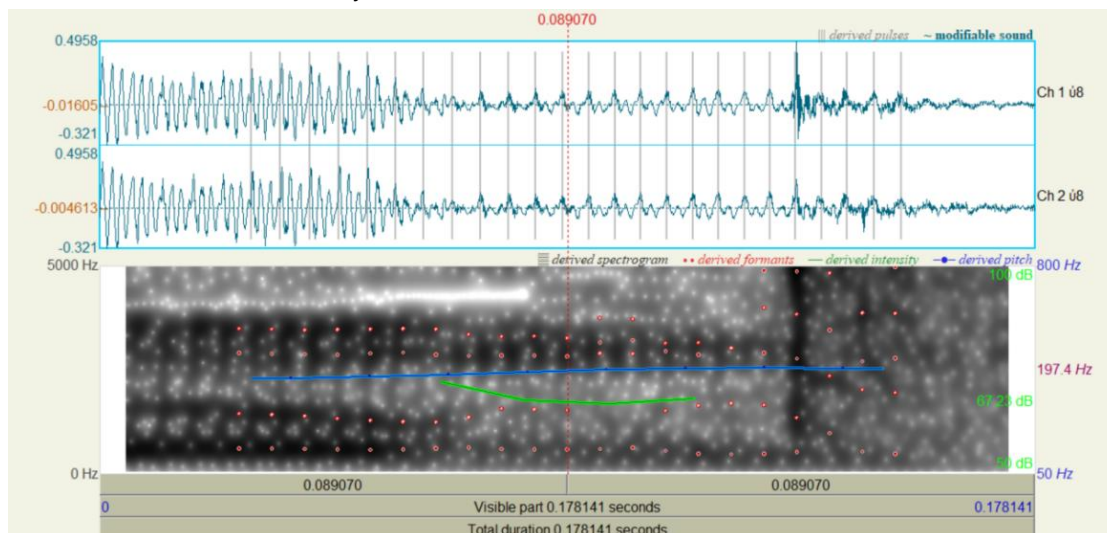


Image 5. Xiaojia's pronunciation of “生”

Palatals (/tɕ/, /tɕʰ/, /ɕ/): With 50 total occurrences and 3 errors (e.g., mistaking a zero initial for /tɕʰ/ in “起”, /tɕʰ/ for /tɕ/ in “居”), the error rate was 6%. Errors included substitutions of zero initials for palatals and aspirated-unaspirated substitutions within palatals (e.g., /tɕʰ/ → /tɕ/). Palatals only require slight elevation of the anterior tongue to touch the hard palate (a small movement range, no tongue-tip involvement), so spasticity has minimal impact on palatal muscle control, leading to a low error rate.

The target consonant in the image below is the palatal affricate /tɕ/, which combines a stop phase and homorganic frication. The spectrogram displays a poorly defined stop release and faint fricative noise distributed broadly across mid-frequencies. The formant transitions are shallow, and the aspiration is minimal. The waveform supports this with a low-amplitude burst and abbreviated frication duration. These deviations indicate articulatory weakening, likely leading to a perceived deaspirated affricate or even a glide-like production.

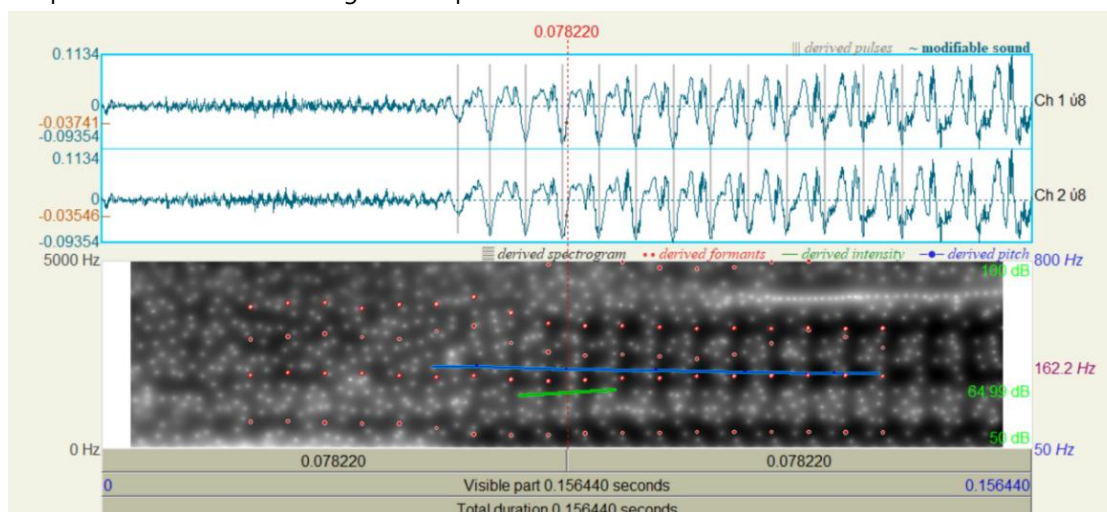


Image 6. Xiaojia's pronunciation of “居”

Velars (/k/, /kʰ/, /x/): With 53 total occurrences and 10 errors (e.g., mistaking /x/ for /f/ in “发”, /x/ in “生”), the error rate was 18.87%. All errors were concentrated in /x/, manifesting as substitutions of /f/, /tʰ/, or /ʂ/ for /x/. /x/ requires velar elevation to form a fricative channel near the soft palate; the velar muscles are among the most spastically affected in Xiaojia, severely limiting this movement and making /x/ the most error-prone velar consonant.

4.3. Error Rates by Manner of Articulation

Consonants were further categorized into 5 groups by manner of articulation (stops, fricatives, affricates, nasals, laterals). Their error rates and characteristics are as follows:

Stops (/p/, /pʰ/, /t/, /tʰ/, /k/, /kʰ/): With 93 total occurrences and 4 errors, the error rate was 4.30%. Errors included aspirated-unaspirated substitutions within stops (e.g., /pʰ/ → /p/) and substitutions of other consonants for stops (e.g., /x/ → /tʰ/). Stops only require brief articulatory contact followed by rapid release—simple, short-duration movements—so spasticity has the least impact on stop production, resulting in the lowest error rate.

Fricatives (/f/, /x/, /ɸ/, /s/, /ʃ/): With 125 total occurrences and 10 errors (e.g., mistaking /x/ for /f/ in “佛”, /x/ for /s/ in “生”), the error rate was 8%. All errors were concentrated in /x/ (8 cases) and /s/ (2 cases), showing substitutions of /f/ for /x/ and /l/ for /s/. Fricatives require sustained articulatory contact to form a narrow channel for frication; spasticity causes unstable channel width (e.g., the velar-soft palate channel for /x/) and insufficient fricative intensity, leading to a higher error rate than stops.

For the syllable “佛”, starting with /f/, the spectrogram should show high-frequency noise above 4 kHz due to labiodental turbulence. However, the acoustic evidence reveals dominant energy in the 1–2.5 kHz region, reminiscent of velar fricative /x/ production. The waveform lacks the irregular high-frequency peaks typical of /f/ and instead shows more rhythmic, lower-frequency oscillations. This pattern reinforces the consistent substitution of /x/ for /f/, highlighting the speaker's reliance on velar articulation amid fronted consonant production difficulties.

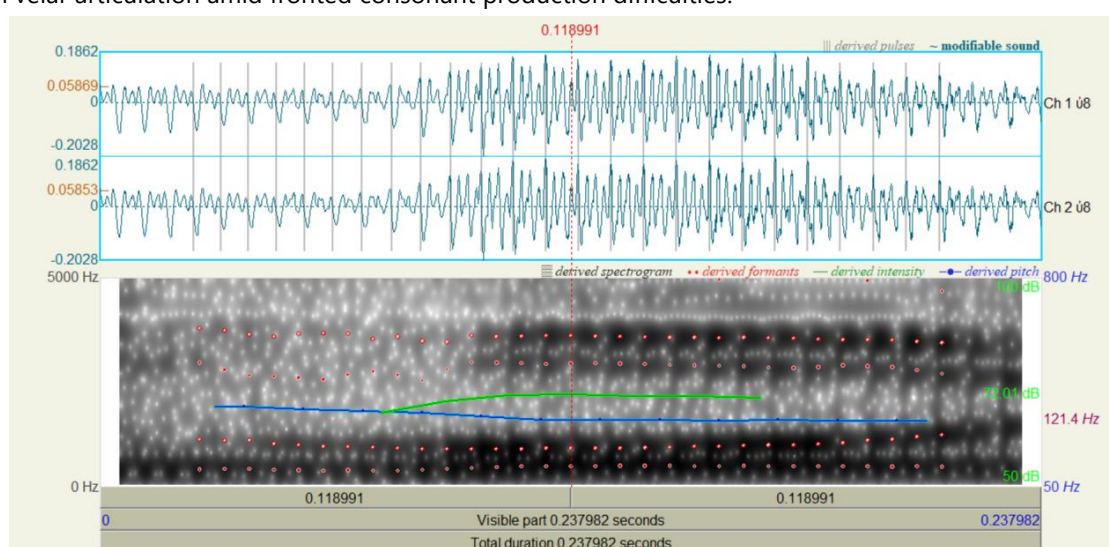


Image 7. Xiaojia's pronunciation of “佛”

Affricates (/tʃ/, /tʃʰ/, /tɕ/, /tɕʰ/, /ts/, /tsʰ/): With 83 total occurrences and 9 errors (e.g., mistaking /ts/ for /tʃ/ in “知”, /tɕʰ/ for /tɕ/ in “居”), the error rate was 10.84%. Errors included alveolar-retroflex substitutions (e.g., /ts/ → /tʃ/), aspirated-unaspirated substitutions (e.g., /tɕʰ/ → /tɕ/), and substitutions of zero initials for affricates. Affricates require rapid “stop-fricative” transitions (e.g., /tʃ/ involves initial retroflex closure followed by gradual release for frication); spasticity impairs movement coordination, disrupting this transition and leading to a higher error rate than fricatives.

Nasals (/m/, /n/): With 50 total occurrences and 5 errors (e.g., mistaking /w/ for /m/ in “慢”, /l/ for /n/ in “能”), the error rate was 10%. Errors included nasal-lateral cross-substitutions (e.g., /n/ ↔ /l/) and semivowel-nasal substitutions (e.g., /w/ → /m/). Nasals require soft palate lowering to open the nasal cavity while forming an oral obstruction; spasticity impairs soft palate control and disrupts nasal-oral airflow switching, resulting in a relatively high error rate.

Laterals (/l/): With 30 total occurrences and 6 errors (e.g., mistaking /z/ for /l/ in “了”, a zero initial for /l/ in “乐”), the error rate was 20%—the highest among all manners. Errors included substitutions of other consonants for /l/ (e.g., /z/ → /l/) and substitutions of /l/ for other consonants (e.g., /l/ → /z/). /l/ requires tongue-tip contact with the alveolar ridge and lateral tongue lowering to form an airflow channel—a complex movement; spasticity causes misaligned tongue-tip contact and insufficient lateral lowering, preventing smooth airflow, hence the highest error rate.

The lateral approximant /l/ in “了” should exhibit a distinctive formant structure with lowered F1 and raised F2 due to lateral airflow. The current spectrogram, however, shows a flattened formant contour, with F2 lower than anticipated and reduced intensity in higher bands. The waveform lacks the sharp rise and fall typical of lateral release, showing instead a more vowel-like gradual onset. These features suggest articulatory inaccuracy in tongue tip positioning and airflow management, resulting in substitutions with vowels or other approximants.

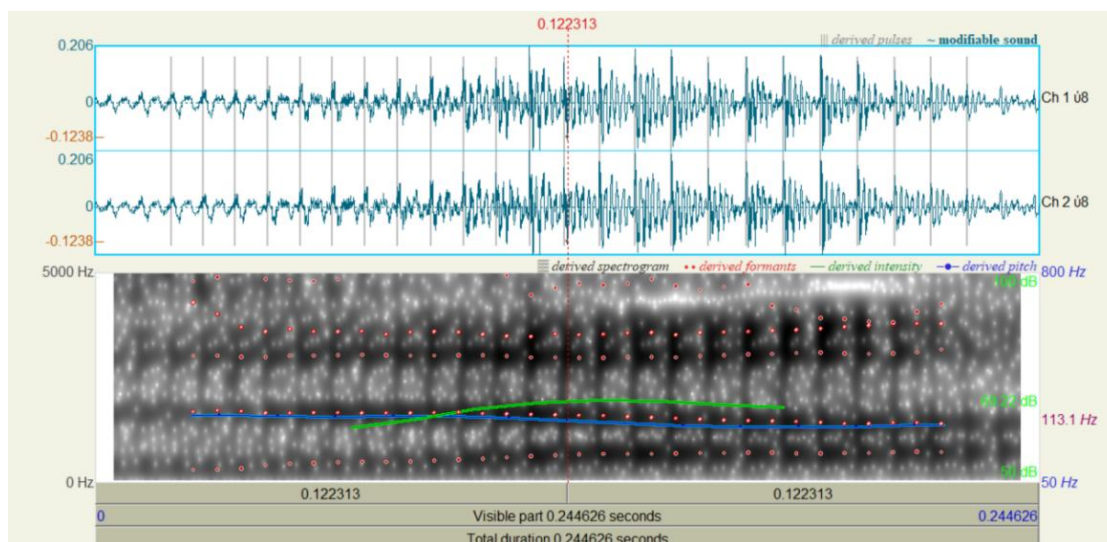


Image 8. Xiaojia's pronunciation of "了"

4.4. Error Types

The analysis of Xiaojia's consonant production errors revealed a clear predominance of one error type, with substitutions accounting for the vast majority of misarticulations. Specifically, substitutions constituted 90.91% of all errors, while distortions accounted for the remaining 9.09%. No omissions were identified in the data, indicating that Xiaojia consistently produced some form of consonant initiation, even when the target sound was not accurately realized.

Substitutions were the most frequent error type and involved the replacement of one consonant with another phonetically identifiable sound. These errors often reflected articulatory simplifications or compensatory strategies due to motor limitations. For instance, the velar fricative /x/ was frequently substituted for the labiodental /f/ (e.g., "发" produced as /xa/), indicating a posterior-to-anterior place shift likely due to difficulty with fine lip-teeth coordination. Other notable substitutions included alveolar-retroflex confusions (e.g., /ts/ → /tʂ/ in "知") and nasal-liquid alternations (e.g., /n/ → /l/ in "能"), which illustrate the impact of spasticity on tongue tip control and airflow direction.

Distortions, though less frequent, involved productions that were not easily categorizable into another phoneme but were perceived as imprecise or unclear. These errors often resulted in weakened articulation, such as faint frication noise in affricates or reduced aspiration in stops. For example, the palatal affricate /tʃ/ in "居" was produced with a weak release and shallow formant transition, making it sound distorted rather than substituted. Distortions typically occurred in consonants requiring sustained articulatory control, such as fricatives and laterals, where spasticity may lead to inconsistent constriction or unstable resonance.

The complete absence of omissions suggests that Xiaojia maintains a relatively high level of articulatory effort and phonological awareness. This pattern aligns with the functional communication strategies often developed by individuals with dysarthria in high-verbal-demand environments.

4.5. Discussion

This study provides a detailed analysis of consonant initial production errors in the speech of Xiaojia, an adult with cerebral palsy. The findings offer valuable insights into the articulatory patterns and adaptive strategies employed by individuals with motor speech disorders in real-world communicative settings.

The high prevalence of substitution errors (90.91%) aligns with previous research on dysarthria, which often reports substitutions as the dominant error type in speakers with CP (Kim et al., 2010; Liu & Chen, 2021). However, the specific patterns observed highlight the role of articulatory complexity and motor control limitations. The higher error rates for posterior consonants (e.g., velars) and complex manners (e.g., laterals) support the notion that sounds requiring precise dorsal control or multi-step articulatory gestures are more vulnerable to disruption in spastic dysarthria (Kim & Gurevich, 2023). This is consistent with Xiaojia's clinical profile, where spasticity likely affects tongue back and soft palate coordination more severely than lip or tip movements.

5. Conclusion

This study characterized the consonant initial articulation of an adult with spastic cerebral palsy (Xiaojia) on the basis of naturalistic public talk show recordings. The overall error rate of 11.51% indicated moderate dysarthria, with errors concentrated in consonants requiring posterior articulation or complex lingual gestures (e.g., /x/, /l/, /f/) and markedly lower rates in anterior or simple consonants. Substitution was the dominant error type (90.91%), followed by distortion

(9.09%), and no omissions were observed, suggesting that Xiaojia consistently maintained articulatory effort despite motor limitations. The findings underscore the influence of articulatory complexity and spasticity on consonant production and demonstrate that non-standard articulation does not preclude effective communication in professional contexts. Theoretically, the study enriches the limited evidence on adult Mandarin-speaking individuals with cerebral palsy; clinically, it offers directions for speech rehabilitation and adaptive communication strategies for adults with dysarthria. Future research may extend the analysis to a larger sample and to non-initial consonants to further verify these patterns.

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