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Phonotactic Competency of Bengali Speaking Children with and without Speech-Language Impairment

Kompetensi Fonotaktik pada Anak-Anak Penutur Bahasa Bengali dengan dan tanpa Gangguan Bicara-Bahasa

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Keywords

phonotactic competency; cluster simplification; autism spectrum disorder; down syndrome; language delay.

Abstract

Development of phonotactic competency in various contexts of phonological constituents is a prerequisite of effective speech-language competency in the native language. This study aims to explore the phonotactic competency of Bengali-speaking children with and without speech-language impairment. A mixed-method approach exploring the nature of phonotactic competency and differences among those competencies was undertaken. A total of 80 children with typical development (20), autism spectrum disorder (20), down syndrome (20), and language delay (20) were recruited for this study. Typically developing participants statistically outperformed ($p < .05$) others regarding the production of ranges of syllable structure, clusters, and consonant types, while significant ($p < .05$) within and between group variability was accounted for in the other groups. Variations in the simplification processes of cluster production and error types across syllable positions were also observed. The findings of the study may facilitate the understanding of phonological development patterns of the study population, suggesting the inclusion of varied cluster simplification patterns to assess phonotactic competence.

Kata kunci

kompetensi fonotaktik; penyederhanaan kluster; gangguan spektrum autisme; sindrom down; keterlambatan bahasa.

Abstrak

Pengembangan kompetensi fonotaktik dalam berbagai konteks konstituen fonologis merupakan prasyarat bagi kompetensi bicara-bahasa yang efektif dalam bahasa ibu. Penelitian ini bertujuan untuk mengeksplorasi kompetensi fonotaktik pada anak-anak penutur bahasa Bengali dengan dan tanpa gangguan bicara-bahasa. Pendekatan metode campuran digunakan untuk mengeksplorasi sifat kompetensi fonotaktik serta perbedaan di antara kompetensi-kompetensi tersebut. Sebanyak 80 anak yang terdiri dari kelompok perkembangan tipikal (20), gangguan spektrum autisme (20), sindrom down (20), dan keterlambatan bahasa (20) direkrut untuk penelitian ini. Peserta dengan perkembangan tipikal secara statistik mengungguli ($p<0,05$) kelompok lain dalam hal produksi rentang struktur suku kata, kluster, dan jenis konsonan, sementara variabilitas yang signifikan ($p<0,05$) di dalam dan di antara kelompok ditemukan pada kelompok lainnya. Variasi dalam proses penyederhanaan produksi kluster dan jenis kesalahan di berbagai posisi suku kata juga teramati. Temuan penelitian ini dapat memfasilitasi pemahaman tentang pola pengembangan fonologis dari populasi penelitian, serta menyarankan penyertaan berbagai pola penyederhanaan kluster untuk menilai kompetensi fonotaktik.

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A. Introduction

Acquisition of speech sound patterns followed by the development of a set of principles that define sound patterns, sound changing, and variation in a language, referred to as phonology (O'Grady et al., 1997; Li, 2025; Davidson, 2006; Yallop & Fletcher, 2007). Phonotactics refers to the permissible composition of phonetic elements within the syllable structure of a specific language. Studies mostly defined phonotactics as the systematic arrangement of phonological units (Crystal, 2011), the limitation and constraint of the concurrence of vowels and consonants (Kreidler, 1989), the rules of co-occurring phonemes within a word (Trask, 2004), distributional restriction, and the admissible syllable patterns of a particular language (Lass, 1984). The knowledge of the phonotactic rules of the native language typically emerges in early infancy (Jusczyk et al., 1993) and is closely linked with the performance of language comprehension and expression (Vitevitch & Luce, 1999), as exhibited in the competence of communication adequacy. Consequently, the perpetuation and the exhibition of appropriate linguistic behaviors and linguistic context establish language as a social practice (Masduqi et al., 2024). Nevertheless, phonotactic development, specifically the development of cluster production, is considered a prerequisite for the development of word formation (morphology) (McLeod et al., 2001).

Up until the age of six, children typically develop their phonotactic capacity to various extents of phonological constituents, from open syllables like CV to more complex and closed syllables like CVCC (Grech, 2000; Babatsouli, 2016). Children with communication disorders like autism spectrum disorders (ASD), Down Syndrome (DS), and developmental language delay (LD) follow deviated articulatory and phonotactic trajectories compared to typically developed children (TD) (Wolk & Edwards, 1993; Wolk & Giesen, 2000; Roberts et al., 2005; Wilkinson, 1998). Therefore, they are manifested as speech sound difficulties even after passing the phonological developmental period. Speech sound or speech production difficulties arise in children with ASD, DS, and LD as a combination of motoric level articulation deficits (Kent & Vorperian, 2013; Chenausky, 2015) and phonological processing errors that are characterized by phoneme distortion, substitution, omission, epenthesis, metathesis, cluster reduction, assimilation, and likely (Wolk & Brennan, 2013; Oweleke, 2022; Raitano Lee et al., 2010; Stoel-Gammon, 2001; Aguilar-Mediavilla et al., 2002).

Wolk & Brennan (2013) found a delayed phonological production along with atypical phonological simplification in children with ASD, which was strongly connected with their further language impairment. The influence of complexity on phonological output in autism was also noted by Tuller et al. (2017) through a word repetition task that asked participants to repeat actual words differing in syllable length and phonological intricacy. Challenges arise when syllabic intricacy is involved. Consonant clusters represent a documented source of complexity and also include internal codas (Manenti et al., 2025). Processes that result in the simplification of intricate syllabic patterns, such as cluster reduction (e.g., mostok → [bu]) and final consonant deletion (e.g., shirt → [sha]), have been noted in spontaneous language samples from certain autistic children experiencing phonological challenges (Manenti et al., 2025).

Individuals with DS exhibit notable deficits in linguistic abilities, leading them to consistently perform better on non-verbal tasks compared to verbal ones (Næss et al., 2011). Initial phonetic and phonological growth resembles that of typical children but occurs at a slower pace (Manipuspika & Sudarwati, 2019). Participants with DS demonstrated an increased occurrence of processes at both levels: segmental (simplifying and omitting trills and fronting) and syllable structure (reducing complex onsets and nuclei and omitting codas) (Diez-Itza et al., 2021). Rupela & Manjula (2007) stated that children with DS have a simplified phonotactic profile in both targeted and conversational speech compared to normal children and children with intellectual retardation, similarly, found by Diez-Itza et al. (2021). They found that DS children tended to make phonological simplifications like consonant deletions, syllable deletions, and cluster reductions. Rupela & Manjula (2007) also mentioned that DS children showed more limitations in using trisyllabic and polysyllabic words than monosyllabic and disyllabic words.

The children with DLD manifest language impairments that cannot be attributed to any identifiable intellectual, organic, or neurological abnormality, nor can they be linked to autism or parental/social neglect (Sohali, 2023). Children experiencing language delay frequently show

challenges in syntax, morphology, and semantics (Shriberg & Kwiatkowski, 1994). While sound acquisition and phonological simplification in children with DLD resemble those in TD children, children with DLD require more time to master CVC syllables and multisyllabic productions (Weiss & Paul, 2010; Roberts et al., 1998; Rescorla & Ratner, 1996). Aguilar-Mediavilla and colleagues (2002) found delayed phonological acquisition in children with LD and specific language impairment (SLI) at the segmental level and syllabic level as well. They found LD children to make syllabic and non-syllabic cluster reduction, consonant deletion in the word initial and word final, and unstressed syllabic deletion.

There is a lack of comparative studies across clinical groups, and the focus on the Bengali Language is particularly limited. Bangla is the seventh most spoken language in the world and contains a complex and distinguishing feature in phonology and phonotactics, with a wide range of sounds along with the syllable structure and consonant clusters (Mandal & Hossain, 2017). But the developmental aspects of phonotactics of Bangla-speaking children have not received adequate attention, like English and other languages, especially in terms of phonotactic development among a non-typical group of the population, which is underreported. In such a pursuit, this study aims to explore the nature of phonotactic competency as well as the cross-group comparison of the nature and competency among Bengali-speaking children with ASD, DS, and LD.

B. Method

A purposive sampling method was employed to recruit 80 participants, categorized into four distinct groups: typically developing (TD) children, children with Autism, children with Down Syndrome, and children with Language Delay (LD). Each group consisted of 20 Bengali-speaking children aged five to nine years, a range selected specifically to examine phonological skills during the critical stage of maturation. Inclusion criteria required participants to have Bengali as their primary language and no documented vision or hearing impairments. To access these populations, three speech-language pathology organizations and a government primary school were contacted. In accordance with organizational policy, participants with neurodevelopmental disabilities and LD had previously undergone diagnostic evaluation by multidisciplinary teams. Following institutional approval, written informed consent was obtained from all parents on behalf of their children.

The study utilized an indigenously developed list of 60 stimuli, ranging from monosyllabic to polysyllabic words, carefully selected to align with the age-appropriate lexicon of the TD group. The linguistic design included both open and closed syllable structures, as well as CC clusters (word-initial and word-medial) and CCC clusters (word-medial). Notably, word-final CC clusters were excluded as they do not occur in the Bengali language. To facilitate data collection, a corresponding list of pictures was developed. For abstract words lacking direct pictorial representation, stimuli were selected based on their prevalence in conversational speech. Furthermore, each syllable pattern featured at least three different words composed of varied phonemes to identify specific difficulties in articulating distinct phonotactic structures.

Data collection procedures were tailored to the specific needs of the participant groups in a controlled, quiet environment. While the TD group engaged in a single-word naming task, children with neurodevelopmental disabilities and LD participated in both picture naming and single-word imitation tasks. This dual approach was necessary to mitigate challenges related to impaired attention and spontaneous speech production often observed in these populations, allowing for a more precise assessment of phonological and articulatory difficulties. During imitation tasks, multiple responses were recorded for each word to identify the perceptually optimal production. Perceptual evaluation was utilized as the primary measure, as it remains a traditionally reliable metric for assessing stimulability.

All responses were audio-recorded using a Sony ICD-PX240 device and subsequently transcribed using the International Phonetic Alphabet (IPA) to identify atypical productions or phonotactic deviations. To ensure data reliability, two independent ratters performed the transcriptions, with inter-rater agreement measured via Cohen's Kappa on 50% of the total dataset. A mixed-methods approach was adopted for data analysis; quantitative group differences regarding the correct

production of syllable patterns, consonants (releasing and arresting), and clusters were analysed using the non-parametric Kruskal-Wallis H test in IBM SPSS version 20, as the data violated normal distribution. Complementarily, a descriptive qualitative approach was employed to analyse vowel and consonant production errors, cluster nature, and any observed simplifying phonological processes.

C. Results and Discussion

Through Table 1, it can be seen that the mean age of the participants fell between 8 and 8.5 years of age, where the intra-group age variability was the least for the TD group.

Table 1. Demographic Information of the participants

Type	Frequency	Percent	Mean Age	Standard Deviation
TD	20	25%	8.15	.34
ASD	20	25%	8.8	1.43
DS	20	25%	8.65	1.36
LD	20	25%	8.49	1.45
Total	80	100%	8.52	

To measure the inter-rater reliability of the transcription using the International Phonetic Alphabet, Cohen's Kappa was employed. An excellent level of agreement between raters was observed as the range of Kappa values fell between .796 and .867 for the 80 sets of transcriptions for the participants. For an excellent agreement, the Kappa value needs to be above 0.75, while a value above 0.6 means acceptable agreement, and a complete agreement is indicated by a value of +1 to measure inter-rater reliability.

1. Group Differences in Syllable Structures

A Kruskal-Wallis H test showed that there were significant statistical differences in correct production of specific syllable structure in naming and imitation task among four groups of participants: VCV (χ^2 (3) = 29.32, p = .001), VCCV (χ^2 (3) = 33.47, p = .003), CCVC (χ^2 (3) = 37.76, p = .003), CVVCV (χ^2 (3) = 32.55, p = .003), CVCCV (χ^2 (3) = 34.59, p = .002), CVCCCV (χ^2 (3) = 38.71, p = .003), CVCCVC (χ^2 (3) = 36.81, p = .003), CCVCVC (χ^2 (3) = 36.34, p = .002), VCVCVC (χ^2 (3) = 32.63, p = .002), CCVCVCVCV(χ^2 (3) = 38.24, p = .003), CVCVCVCCV (χ^2 (3) = 37.55, p = .001), CCVCCV (χ^2 (3) = 18.47, p = .002).

Post Hoc comparisons of mean ranks using Dunn's test were employed to further investigate the nature of differences. The TD group showed significant differences (p< 0.005) from other groups across all complex structures. However, the DS group differed with the ASD and LD groups regarding the VCV (ad̪a), VCCV (alt̪a), and CCVC (tren) structures (p< 0.005). The DS group also differed significantly from the ASD group regarding the CVVCV (nouka) and VCVCVC (anarɔʃ) structure. All three clinical groups showed no discrepancy regarding the CVCCV (tʃɔʃma), CCVCCV (briʃti), CCVCVC (probal), CVCCVC (kʰɔrgoʃ), and CVCCCV (dʒɔnt̪ro) structure. Mean ranks are presented in Table 2.

Table 2. Mean Rank of the Participants across Syllable Structures

Syllable Structure	Mean Rank			
	TD	ASD	DS	LD
VCV	30.41	40.42	36.45	38.75
VCCV	31.45	42.25	39.64	37.74
CCVC	33.69	43.31	37.25	41.72
CVVCV	29.25	39.63	35.81	36.77
CVCCV	34.44	42.35	36.97	39.87
CCVCCV	34.91	44.97	41.52	44.41
CVCCCV	33.37	43.74	41.43	42.35
CCVCVC	31.37	42.45	36.39	38.57
CVCCVC	33.67	41.53	34.91	42.34
VCVCVC	29.41	42.34	37.56	41.43
CCVCVCVCV	30.66	43.33	42.49	44.35
CVCVCVCCV	31.42	44.45	36.67	43.92

Statistically significant differences in the correct production of open and closed Syllables, releasing and arresting consonants as well as consonant clusters were found in a non-parametric Kruskal-Wallis H test for the four groups of participants: open syllables (χ^2 (3) = 29.47, p = .003), closed syllables (χ^2 (3) = 32.52, p = .003), releasing consonants (χ^2 (3) = 33.47, p = .004), arresting consonants (χ^2 (3) = 34.21, p = .003), CC cluster in word initial position (χ^2 (3) = 34.67, p = .002), CC cluster in word medial position (χ^2 (3) = 33.91, p = .003), CCC cluster in word medial position (χ^2 (3) = 34.77, p = .002).

Post Hoc comparisons of mean ranks using Dunn's test were employed to further investigate the nature of differences. The TD group significantly differed from the other groups (p< 0.005) regarding the production of syllable structures, clusters, and consonants. The DS group showed significant differences with the ASD and LD group (p< 0.005) in both the open and closed syllables, as well as releasing and arresting consonants. The ASD group only showed significant differences from the LD group regarding closed syllables (p< 0.005). The TD group exhibited significant differences from the other three groups in CC initial cluster, CC medial cluster, and CCC medial cluster production (p< 0.005). The DS group differed significantly from the ASD group in this regard (p< 0.005). Regarding the CCC medial cluster production, the DS group differed significantly from both the ASD group and the LD group (p< 0.005). Mean ranks are presented in Table 3. These significant differences are further elaborated through a qualitative analysis of the syndrome-specific error profiles.

Table 3. Mean Rank of the Participants Regarding Syllable Types, Consonants, and Clusters

Production Types	Mean Ranks			
	TD	ASD	DS	LD
Open Syllables	28.84	36.47	30.63	32.32
Closed Syllables	29.31	39.91	32.57	34.82
Releasing Consonants	28.55	34.45	29.71	31.35
Arresting Consonants	28.62	40.41	38.72	41.44
CC initial clusters	29.67	41.44	35.76	38.89
CC medial clusters	29.91	41.97	37.74	36.32
CCC medial clusters	30.77	43.55	37.63	42.32

2. Qualitative Analysis of Error and Simplification Processes

For the TD group of participants, the production and the maintenance of the sequences of vowel and consonant indicated no significant consistent type of errors. Inconsistent errors were observed in the production of longer sequences consisting of polysyllabic structures such as CCVCVCVCV (prodʒapoʊ̯) and CVCVCVCCV (dʒɔlohosʊ̯).

For the ASD group, noticeable difficulties were observed across groups of sounds. Consistent errors in the production of vowels included distortion of high front and high back vowels such as /i/, /u/, and /o/. In the production of open syllables, the omission of the final sound of words consisting of more than one syllable was prevalent. Diphthong production was difficult for this group of participants, which was primarily observed in the CVC structure, where diphthongs such as /ou̯/ were consistently produced and perceived to be distorted and sounded somewhat as /o/ instead. A similar nature was consistent for the CV syllable structure, where the diphthong /au̯/ was continuously distorted to be sounded as /ao̯/. Bilabial sounds were continuously substituted in the releasing and arresting position of a syllable structure, where the substitution of aspirated bilabials /p^h/, /b^h/ was dominantly unaspirated as the arresting consonant of a syllable structure. Similar types of errors were also observed in the production of dental sounds for this group. The substitution of aspirated alveolar and post-alveolar sounds with their unaspirated equivalents was consistently observed for this group in the releasing position. Production of palatal sounds indicated both substitution and distortion error types. Aspirated palatals such as /t$ʃ^h$/, /d$ʒ^h$/ were relatively consistently substituted with their unaspirated equivalents, where the substituted sounds were further distorted, with the quality of distortion indicating relatively reduced voicing quality and reduced quality of articulatory contact. The releasing velar consonants were constantly substituted for their aspirated equivalents.

Interestingly, the arresting consonants of a multisyllabic structure were omitted or unaspirated in an inconsistent manner for this group of participants.

For the DS group, vowel production errors exhibited variability where high back vowels such as /u/ and a specific vowel /æ/ were continuously distorted. Distortion of diphthongs /oi̯/ and /ou̯/ was dominant in the CV and CVC structure. Constant substitution of aspirated bilabial releasing, and arresting consonants was observed. The substituted unaspirated equivalents were further distorted, which was realized as weak articulation. Dental sounds exhibited constant substitution errors for their aspirated variants. Variability in the production of unaspirated dental sounds was not observed. Interestingly, substitution was the major error type for alveolar and post-alveolar consonants, as both releasing and arresting sounds, where the substituted sounds represented a dental unaspirated sound regardless of the target sound to be aspirated or unaspirated in all syllable structures. The dominant error type for palatal sounds for this group was distortion. Palatal productions were dominantly realized as fricatives regardless of the target sounds being affricates in every case. Despite constant substitution of affricates (/tʃ/, /tʃʰ/, /dʒ/, /dʒʱ/) with fricatives, the realization of all palatal production was to be weakly articulated and distorted with decreased voicing quality. Both releasing and arresting aspirated velar consonants were substituted with their unaspirated equivalents, where all the velar productions were realized to be fronted. Significantly, relatively consistent omission of arresting consonants was observed for this group regarding the production of multisyllabic structures such as VCVCVC and CCVCVCVC.

For the LD group, inconsistent errors in the production of vowel and diphthong sounds across all syllable positions were evident in the manner of distortion and omission. In the production of open syllables, omission of the final sound of words consisting of both monosyllabic and multisyllabic structures was frequently observed in an inconsistent manner. Bilabial sounds, as the arresting sound of a syllable structure, were omitted at the syllable final position without a consistent indication of substitution. Inconsistent substitution of dental aspirated consonants across syllable structures was also observed with a similar indication of omission at syllable final position, regardless of structure, in an inconsistent manner. Consistent substitution of alveolar consonants with their unaspirated equivalents was dominant for this group of participants. Omission of this group of sounds as arresting consonants of a syllable structure followed the same manner as bilabial and dental sounds. Palatal sound production exhibited substitutions of unaspirated equivalents for aspirated sounds. Interestingly, this group of sounds was not omitted in the arresting position to a noticeable extent. The production of velar sounds exhibited the same nature as palatal sounds. While almost all groups of sounds were omitted in the arresting position of a syllable for this group of participants, palatal and velar sounds exhibited a deviated nature from other groups of sounds.

Across a continuum of articulatory places, Bengali consonants are categorized into both voiced and voiceless unaspirated equivalents of aspirated phonemes. A rare phonological hallmark of the Bengali language is the voiced aspirated stops (e.g., /bʱ/) (Sarkar & Sreeparna, 2023). Lower accuracy, higher rates of substitution and desperation of aspirated phonemes have been reported in children with Autism, Developmental Language Disorder, and children and adolescents with Down Syndrome (Feng et al., 2022; Muldawati et al., 2024; Liu et al., 2020). Notably, such substitutions frequently lead to phonemic changes, resulting in a deviation from intended meaning, as aspiration is a marked feature of the Bengali language.

Table 4. Dominant Error Types across Syllable Positions

Sound Groups	Error types regarding specific groups			
	TD	ASD	DS	LD
Vowels		Omission (Final Position), Distortion	Distortion	Omission (Final Position), Distortion
Diphthongs		Distortion	Distortion	Distortion
Bilabial		Substitution	Substitution, Distortion	Omission (Final Position)
Dental		Substitution	Substitution	Substitution, Omission (Final position)
Alveolar/Post-alveolar		Substitution, Distortion	Substitution, Distortion	Substitution, Omission (Final Position)
Palatal		Distortion, Substitution	Distortion, Substitution	Substitution
Velar		Substitution	Substitution	Substitution

Differences in cluster production were evident across groups, where within-group variation was not to a greater extent. For the TD group, CC initial cluster production exhibited the least difficulty. The dominant simplification process regarding the initial CC cluster for this group was Epenthesis. This process was also dominant for a CC initial cluster where /r/ is the second member of a cluster. Inconsistent cluster reduction was also observed for this group, with /k/ as the first member of a cluster. For the CC initial cluster, the ASD group exhibited cluster reduction regardless of sound combination as the dominant simplifying process. While cluster reduction was also dominant for the DS and LD group for the CC initial cluster, these two groups often used the process of Epenthesis for this cluster. For the CC medial cluster, the TD group often used Epenthesis as the primary simplification process. Significantly, for an r cluster where /r/ is the second member, Gemination of the first member in an isolated manner, as well as the gemination of the first member along with the presence of /r/ as the second member, was observed. Similar to the CC initial cluster, the ASD group exhibited cluster reduction as the dominant simplifying process. For the DS group, the production of CC medial cluster involved Epenthesis as the primary simplifying process, whereas Gemination also occurred regardless of the presence of an r-cluster. The LD group primarily relied on cluster reduction for this type of cluster. The use of Epenthesis was also observed for this group in an inconsistent manner. Regarding the CCC medial cluster, the TD group consistently relied on Epenthesis as the primary simplification process, where the insertion of a vowel sound was observed before the final consonant of the CCC cluster. The ASD group exhibited the process of cluster reduction in this case, also. Interestingly, the DS group followed the same process as the dominant simplifying process for the CCC medial cluster. A similar pattern was also observed for the LD group regarding the CCC medial cluster. Significantly, among the sound combinations for these three types of clusters, the r-cluster was particularly difficult for the participants across groups. A prevalent presence of /r/ cluster reduction is present in the literature, with longer persistence and frequency documented for children with phonological disorders (Holm et al., 2021). However, the pattern of error can vary across languages. Nonetheless, the acquisition of these clusters is most challenging across languages (Gerrits, 2010).

Table 5. Dominant Simplifying Errors across Cluster Productions

Cluster Types	Simplification processes of clusters regarding specific groups			
	TD	**ASD**	**DS**	**LD**
CC initial	Epenthesis	Cluster reduction	Cluster reduction, Epenthesis	Cluster reduction, Epenthesis
CC medial	Epenthesis, Gemination	Cluster reduction	Epenthesis, Gemination	Cluster reduction, Epenthesis
CCC medial	Epenthesis	Cluster reduction	Cluster reduction	Cluster reduction

The findings of the study reveal group-specific disparities in syllabic production accuracy across tasks, with the typically developing (TD) group consistently outperforming clinical groups (ASD, DS, LD) in nearly all syllable structures (VCV, VCCV, CCVC, CVVCV, VCVCVC, CVCCV, CCVCCV, CCVCVC, CVCCVC, CVCCCV). This aligns with established literature linking atypical phonological working memory and articulatory planning to clinical populations (Mettler et al., 2022; Faught et al., 2016; Wynn et al., 2022). Notably, the TD group's lower mean ranks across tasks suggest more efficient phonological encoding and motor execution, likely due to neurotypical maturation of speech-motor networks.

The findings have also identified syndrome-specific patterns in syllabic production, particularly in simpler structures like VCV, VCCV, and CCVC, where the DS group showed greater difficulty than the ASD and LD groups, which is likely due to syndrome-specific motor speech deficits such as dysarthria associated with DS. In contrast, similar performance between ASD and LD groups suggests overlapping linguistic-phonological challenges, potentially linked to shared executive functioning issues. Furthermore, in more complex vowel-based structures like CVVCV and VCVCVC, the DS group diverged significantly from ASD, reflecting differing underlying mechanisms: prosodic planning issues in ASD versus vowel prolongation difficulties associated with hypotonia in DS.

In highly complex syllable structures such as CCVCVCVC and CVCVCVCCV, all clinical groups (ASD, DS, LD) performed significantly worse than the typically developing (TD) group, supporting the phonotactical complexity hypothesis (Anttila, 2008). The lack of notable differences among the clinical groups suggests that increasing syllabic complexity intensifies shared processing challenges (such as working memory demands) rather than highlighting syndrome-specific deficits.

Hierarchical patterns have been observed in syllable and consonant production, with the typically developing (TD) group consistently achieving higher accuracy across all syllable types (open and closed), consonant positions (releasing and arresting), and cluster forms (CC and CCC). In contrast, clinical groups (ASD, DS, LD) displayed distinct error profiles shaped by syndrome-specific motor-linguistic impairments and increased vulnerability to phonological complexity, highlighting the interplay between developmental disorder type and linguistic task demands.

In open syllables, the DS group's significant struggles compared to ASD and LD may stem from oral hypotonia impairing vowel prolongation (Gama, 2016), where ASD and LD groups' relative proficiency may indicate intact basic syllabic framing but potential deficits in higher-order prosody. Whereas, in closed syllables, the typically developing (TD) group showed dominance in producing "CVC" structures, consistent with expected mastery of coarticulation skills by school age (Kim & Davis, 2015). The DS group's greater difficulty in distinguishing final consonants may reflect apraxic tendencies affecting consonant placement (Coêlho et al., 2021). Differences between ASD and LD groups—such as ASD children substituting initial sounds in words—suggest varying degrees of phonological processing and executive limitations, with ASD and LD each presenting distinct underlying cognitive profiles impacting speech production.

The typically developing (TD) group demonstrated superior accuracy in both releasing (syllable-initial) and arresting (syllable-final) consonants, reflecting mature articulatory timing and coordination. In contrast, the DS group showed greater difficulty than ASD and LD in both positions, which may be attributed to dysarthria-related challenges with voicing control and motor execution, consistent with known speech motor impairments in Down syndrome.

The TD group showed strong accuracy in CC clusters, reflecting solid phonotactic knowledge, while DS struggled more with initial clusters due to motor planning issues, and ASD showed medial cluster errors linked to phonological simplification etiologies. In CCC medial clusters, ASD had the most difficulty—most likely due to working memory overload in complex sequences—while LD showed intermediate performance, often using vowel epenthesis as a compensatory strategy.

The TD group's near-ceiling performance in vowel and consonant production in most syllable structures aligns with the typical maturation of coarticulatory precision and phonotactic knowledge (Kim & Davis, 2015). But the complexity-driven inconsistencies in polysyllabic sequences suggest working memory overload rather than motor deficits, consistent with age-typical resource limitations.

The ASD group showed consistent distortions of high front and high back vowels and diphthongs, which may reflect prosodic planning deficits (Patel et al., 2019) tied to cerebellar-thalamocortical circuit atypicality. Their substitution of aspirated consonants in syllable margins may stem from sensory-motor integration difficulties, potentially related to atypical oral proprioception. Neutralization of aspirated alveolars and affricate-to-fricative shifts indicates phonological rule generalization errors, common in ASD linguistic profiles (Bourzeg, 2020; Miniscalco et al., 2024).

The DS group showed frequent diphthong distortions in CV and CVC structures, and weakly articulated substitutions of aspirated bilabials in both arresting and releasing positions. It indicates their challenges in reduced articulatory precision (Ongun et al., 2017) and coordinating vowel transitions. The DS group consistently substituted aspirated dental, alveolar, and post-alveolar sounds with unaspirated dentals, indicating selective aspiration difficulties and a default substitution strategy.

Palatal affricates were distorted into weakly voiced fricatives, and velar aspirates were fronted and unaspirated, which may be caused by weak phonological planning and simplification tendencies. Frequent omission of arresting consonants in multisyllabic words and dominant substitution/distortion patterns suggest broader developmental speech impairments regarding their articulatory shifts.

The LD group showed inconsistent vowel and diphthong production with frequent distortions and omissions, suggesting poor phonemic awareness (Moraleda-Sepúlveda et al., 2022) and unstable phonological representations. LD group's inconsistent omissions of final sounds in monosyllabic and multisyllabic open syllables suggest a general difficulty with phonological closure rather than a systematic substitution process. Omission of bilabial and dental aspirated consonants in syllable-final positions (without consistent substitution) also highlights the unstable nature of phonological planning in the LD group. In the LD group, alveolar consonants were often substituted with unaspirated forms and frequently omitted in syllable-final positions, while palatal and velar sounds, though simplified, were less often omitted. This pattern suggests that phonological planning and articulation in children with learning disabilities (LD) are influenced by both motor and perceptual factors. The frequent omission and inconsistent substitution of alveolar consonants indicate instability in phonological representation and difficulty with articulatory sequencing, particularly in syllable-final positions. In contrast, the relative preservation of palatal and velar sounds, despite simplification, implies that certain sounds may be easier to retain due to lower articulatory complexity or higher perceptual salience.

Consonant cluster production showed distinct group differences with minimal within-group variation. The TD group had the highest accuracy in CC initial clusters, often using epenthesis—especially in /r/-containing clusters—and occasional, less consistent reduction (e.g., clusters initiating with /k/). In contrast, the ASD group consistently reduced clusters across all types, reflecting a generalized difficulty with complex sequences and aligning with broader phonological simplification patterns typical in ASD.

The DS and LD groups both mainly used cluster reduction for CC initial clusters, with frequent epenthesis in clusters containing /r/. This pattern indicates both DS and LD groups' motor planning and phonological processing challenges, making cluster reduction a simpler strategy, while epenthesis helps ease their articulation by inserting a vowel to break up difficult consonant sequences in CC initial clusters. The articulation pattern of the /r/ cluster in Bengali displays a distinct nature due to the adaptation of English loanwords and native cluster formation across dialects. The most notable peculiarities in the simplification processes are influenced by varying strategies across dialects and the position of the cluster. These can negatively influence the existing motor difficulties for children with DS and further complicate the phonological processing of children with LD.

In CC medial clusters, the findings of the study revealed developmental differences in phonotactic processing. the typically developing (TD) group primarily used epenthesis to simplify production. For r-clusters, they also showed gemination of the first consonant, reflecting advanced and flexible phonological strategies. In contrast, the ASD group consistently applied cluster reduction for CC medial clusters, mirroring the pattern observed in CC initial clusters. This suggests a general difficulty with maintaining complex consonant sequences, possibly due to reduced phonological processing capacity. However, the Down syndrome (DS) group showed a preference for Epenthesis, similar to the TD group, and demonstrated Gemination irrespective of /r/-involvement. This reflects a varied but structured approach to cluster simplification. The LD group relied primarily on cluster reduction, with Epenthesis appearing inconsistently, indicating less stable or rule-governed phonological strategies.

For CCC medial clusters, Epenthesis was the consistent simplification strategy in the TD group, typically involving vowel insertion before the final consonant. This points to a more phonologically aware strategy to manage increasing complexity. The ASD, DS, and LD groups all predominantly used cluster reduction for CCC clusters, reinforcing the challenge posed by high cluster complexity. Across all cluster types, r-clusters were notably more difficult for all groups. These findings highlight the impact of both cluster complexity and specific segmental features on phonotactic expression, with implications for intervention focused on stabilizing and supporting cluster development in children with speech and language disorders. The qualitative findings provide direct evidence on the impaired phonotactic competence observed across the study groups that can be attributed to ASD groups' inconsistent phonological mapping and motor planning differences, DS groups' oral motor differences and weak phonological working memories, and the LD groups' impaired phonological awareness.

Besides the understanding of the phonotactics of the children with ASD, DS, and LD, who are also a clinical group who take clinical support for their language development from speech and language development-related professionals, this will help them to make evidence-based clinical decisions for the service and develop clinical tools for this cultural and linguistic group of Bangla-speaking people.

D. Conclusion

The findings of the study reveal consistent performance advantages for the TD group across all linguistic tasks. Clinical groups demonstrated both shared and syndrome-specific patterns of difficulty, highlighting the impact of cognitive, motor, and perceptual factors on speech production. DS children showed pervasive motor planning and articulatory precision issues, which are most likely linked to hypotonia and dysarthria. The ASD group exhibited phonological simplification, sensory-motor integration challenges, and prosodic planning deficits. LD participants displayed instability in phonological representations and inconsistent articulatory strategies, which reflect underlying executive and perceptual processing difficulties. These findings may help advance the current knowledge base of phonotactic processing in neurodevelopmental disorders and lay the groundwork for culturally and linguistically appropriate clinical tools and intervention strategies for Bengali-speaking populations.

However, the present study has several limitations. Firstly, the sample size within each diagnostic group was relatively small, which may limit the generalizability of the findings. Larger and more diverse samples may ensure robust cross-population comparisons. Secondly, while the study controlled for chronological age, it did not account for variation in cognitive or language developmental levels within the clinical groups, which may have influenced performance outcomes. Additionally, a cross-sectional design restricts the ability to assess developmental trajectories or causal relationships in phonological acquisition. Longitudinal studies may provide deeper insight into how phonotactic skills evolve over time in these populations.

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