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Research Note

A Preliminary Investigation of Within-Word Silent Intervals Produced by Children With and Without Neurodevelopmental Disorders

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ABSTRACT

Purpose: The categorization of silent intervals during speech production is necessary for accurate measurement of articulation rate and pauses. The primary purpose of this preliminary study was to examine the within-word silent interval associated with the stop closure in word-final stop consonants produced by children with and without neurodevelopmental disorders.
Method: Seven children diagnosed with either cerebral palsy or Down syndrome (i.e., children with neurodevelopmental disorders) and eight typically developing children produced a reading passage. Participants were between the ages of 11 and 16 years. Fifty-eight words from the reading passage were identified as having word-final stop consonants. The closure duration of the word-final stop consonant was calculated, both in absolute duration and percent pause time. The articulation rate of the entire passage was calculated. The number of closure durations that met or exceeded the minimum duration threshold to be considered a pause (150 ms) was examined descriptively.
Results: Children with neurodevelopmental disorders produced significantly longer closure durations and significantly slower articulation rates than typically developing children. Children with neurodevelopmental disorders produced closure durations that met or exceeded the minimum duration threshold of a pause, but typically developing children, generally, did not.
Conclusion: These data indicate the need to examine the location of silent intervals that meet the minimum duration threshold of a pause and correct for articulatory events during the measurement of articulation rate and pauses in children with neurodevelopmental disorders.

Speech production requires the precise coordination of multiple speech subsystems (respiratory, laryngeal, resonance, articulatory) during sequences of sounded and silent intervals. Speech rate and its component parts, articulation rate (i.e., the amount of time taken to articulate a given message) and pauses (i.e., silent intervals), are an outcome of this precise coordination. Neurodevelopmental disorders, such as cerebral palsy (CP) and Down syndrome (DS), often result in changes to the speech motor system that impact the timing and execution of speech movements (i.e., dysarthria). Children with CP consistently demonstrate slower speech rates due to both slower articulation rates (Allison & Hustad, 2018; DuHadway & Hustad, 2012; Nip, 2013; White et al., 1994, 1995) and increased pause time (Darling-White et al., 2018) as compared to typically developing (TD) children. Children with DS present a more complicated picture. Auditory-perceptual and objective data have described speech rate as too fast, adequate, or too slow (Chapman et al., 1998; Jones et al., 2019; Kent et al., 2021; Kent & Vorperian, 2013; Wilson et al., 2019). Regardless of the direction of rate impairment, speech and articulation rate are among some of the only acoustic variables that routinely distinguish children with dysarthria from TD children or children with other speech sound disorders (Allison & Hustad,

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2018; Hodge & Gotzke, 2014) and distinguish children with neurodevelopmental disorders who exhibit dysarthria from children with neurodevelopmental disorders who do not exhibit dysarthria (Hustad et al., 2010, 2019).

Given their clinical significance, accurate measurement of articulation rate and pauses is of the utmost importance. Articulation rate is calculated by measuring the duration of a speech segment exclusive of pauses and dividing by the number of syllables produced. Pauses are defined as a silent interval that is greater than or equal to a minimum duration threshold, typically ranging from 150 to 250 ms (e.g., Allison & Hustad, 2018; Darling-White & Banks, 2021; Darling-White & Jaeger, 2023; Green et al., 2004; Mahr et al., 2021; Redford, 2014). While identification of a silent interval that meets a minimum duration threshold seems like a straightforward measurement, the location of these silent intervals complicates matters. Silent intervals are associated with a multitude of communicative events, including articulation, breathing, disfluency, syntax, prosody, and cognitive load (e.g., Darling-White & Jaeger, 2023; Goldman-Eisler, 1968; Grosjean & Collins, 1979; Huber et al., 2012; Mitchell et al., 1996; B. Patel et al., 2023; Price et al., 1991), and the location of these silent intervals helps determine how the silent interval will be perceived by the listener. For example, between-words silent intervals that are associated with major syntactic boundaries (i.e., independent clause) can be interpreted as a speaker signaling the end of a complete thought. In contrast, within-word silent intervals are never associated with syntactic boundaries and are most often interpreted as being related to articulatory events (e.g., stop closures).

There is no standard method for the categorization of silent intervals based on location in the speech production literature. In too many instances in the literature, there is no discussion of the handling of between-words versus within-word silent intervals in the measurement of pauses. When it was discussed, two approaches were found in the literature involving individuals (adults or children) with speech motor impairment. One approach considered all silent intervals that reached a minimum duration threshold (≥ 200 or 250 ms) as a pause regardless of their location (e.g., Allison et al., 2019; Green et al., 2004). Pauses were identified by an automated MATLAB program, and pause location was not reviewed by a research team member. Automated programs of this nature are attractive because they allow for quick analysis of large data sets. However, if an articulatory event, such as a stop closure, meets or exceeds the minimum duration threshold, it would be counted as a pause and removed from the measurement of articulation rate, thus potentially overestimating articulation rate and pauses. The other approach (taken by the first author and her research team) was to consider only between-words silent intervals that reached a minimum duration threshold (≥ 150 ms) as pauses (Darling-White & Banks, 2021; Darling-White & Jaeger, 2023). Within-word silent intervals that reached the minimum duration threshold were only counted as pauses if there was kinematic and/or acoustic evidence of a breath. Otherwise, the within-word silent interval was viewed as an articulatory event. This approach is more time-consuming because it requires a research team member to examine the location of each identified pause and its linguistic context to decide whether to count the silent interval as a pause. Deciding whether a within-word silent interval is associated with an articulatory event as opposed to a disfluency or cognitive processing issue is not always straightforward, introducing subjectivity into the measure as well. Thus, this approach has the potential to underestimate articulation rate and pauses.

Appropriate categorization of silent intervals is an important methodological question as it impacts the calculation of articulation rate and pausing, significant features for the differential diagnosis of dysarthria. Additionally, appropriate categorization of silent intervals is necessary for a detailed examination of the potential acoustic contributors to intelligibility. Within-word silent intervals that meet or exceed the minimum duration threshold of a pause could interfere with a listener's ability to appropriately identify the word boundary. Studies involving adults with dysarthria demonstrate the importance of word boundary identification on measures of intelligibility (e.g., Liss et al., 1998, 2000). Furthermore, pauses located at boundaries unrelated to syntax contribute to ratings of the severity of the speech impairment in adults with dysarthria (Darling-White & Huber, 2020).

The frequency of within-word silent intervals meeting minimum pause duration thresholds in the connected speech of children with neurodevelopmental disorders is unknown. Therefore, the potential impact of the inclusion or exclusion of these silent intervals as pauses on measures of articulation rate and pausing is unknown. As a first step in the investigation of the methodological impact of the categorization of within-word silent intervals, this study investigated the within-word silent interval associated with the stop closure in word-final stop consonants during a reading passage produced by children with and without neurodevelopmental disorders. This type of within-word silent interval was chosen because it would be measurable, consistent, and clearly associated with articulation. A "complete stop" is characterized by an identifiable hold portion (i.e., stop closure) followed by release of that hold (Crystal & House, 1988b). Complete stops occur in over 50% of words with stop consonants (Crystal & House, 1988b) and thus are a consistent behavior across children with and without neurodevelopmental disorders. Articulation rate was included as a dependent variable, in addition to closure duration, to provide a fuller picture of articulatory function during the connected speech task. Inferential and descriptive statistics were used to address the following research questions:

1. Do children with neurodevelopmental disorders produce longer closure durations than TD children?
2. Do children with and without neurodevelopmental disorders produce closure durations that could be classified as pauses (≥ 150 ms)?

The most commonly reported rate impairment in children with neurodevelopmental disorders regardless of etiology is slow rate (though there can be significant heterogeneity). As a result, it was hypothesized that children with neurodevelopmental disorders would produce longer closure durations (both in absolute terms and in terms of percentage of time) and demonstrate slower articulation rates than TD children. It was also hypothesized that children with neurodevelopmental disorders would produce closure durations that could be classified as pauses (≥ 150 ms), but TD children would not.

Method

Participants

Seven children diagnosed with a neurodevelopmental disorder (two boys and five girls) and eight TD children (three boys and five girls) participated in the current study. These children were part of a larger parent study, and their data appear in previous publications (Darling-White, 2022; Darling-White & Jaeger, 2023; Kovacs & Darling-White, 2022). The data presented in the current study are unique. Four of the children with neurodevelopmental disorders were diagnosed with CP, and three of the children with neurodevelopmental disorders were diagnosed with DS. The mean age of the children with neurodevelopmental disorders was 13;6 (years;months), with a range of 11;9–16;1. The mean age of the TD children was 13;2, with a range of 11;5–16;2. Prior to data collection, legal guardians provided written consent, and children provided verbal assent. All study procedures were approved by the University of Arizona Human Subjects Review Board (Protocol 16055837A005).

Demographic characteristics of the children with neurodevelopmental disorders, including age, race, ethnicity, native language, language impairment status, speech motor impairment status, intelligibility, gross motor impairment (children with CP), and adaptive behavior skills (children with DS), are presented in Table 1. These demographic characteristics were not used as inclusionary or exclusionary criteria but, rather, are a way to characterize our sample to allow for cross-study comparison. The classification of speech motor impairment was made by the first author, a certified speech-language pathologist using perceptual assessment during a variety of connected speech tasks (e.g., conversation, reading, single-sentence production). All of the children with neurodevelopmental disorders, except two children with CP, demonstrated speech motor impairment. The children with CP and no speech motor impairment were included in the study because children with CP and no speech motor impairment can still demonstrate speech differences when compared to TD children (Hustad et al., 2012, 2019).

All children with CP, except F09CP, passed a bilateral pure-tone hearing screening at 20 dB HL for 500, 1000, 2000, and 4000 Hz. F09CP did not have a history of failed hearing screenings, and her parents did not have any concerns. Only one of the children with DS participated in the hearing screening due to time constraints. F05DS had an elevated threshold of 25 dB at 500 Hz in the right ear but passed at all other frequencies. F01DS wore bilateral hearing aids, and their parents had no concerns about their hearing that were not addressed by the hearing aids. No parent concerns regarding hearing status were reported for F07DS.

TD children were included in the present study if they were proficient speakers of American English and demonstrated typical speech, language, and hearing function. Based on the perceptual assessment of the first author, all TD children demonstrated typical speech production skills. Each TD child demonstrated average or above average language scores as determined by the core language score of the Clinical Evaluation of Language Fundamentals–Fifth Edition (Wiig et al., 2013). All TD children passed a pure-tone hearing screening at 20 dB HL for 500, 1000, 2000, and 4000 Hz bilaterally.

Acquisition of Speech Samples

Acoustic data were collected within a period of 30–45 min at the Motor Speech Research Laboratory at the University of Arizona. During this time, participants completed up to six different speech tasks, the order of which was counterbalanced across participants. Participants were given frequent breaks to prevent fatigue and increase compliance.

Equipment

The acoustic signal was transduced via an omnidirectional headset microphone (Shure WBH53) with a flat frequency response up to 20 kHz and recorded to a digital audio recorder (Marantz PMD671) with a compact flash card. The mouth-to-microphone distance was a constant 6 cm. The acoustic signal was transferred to a computer

Table 1. Participant demographic information.

Participant	Age	Race/ethnicity	Native language	Language impairment	Speech motor impairment	Intelligibility	Type of CP	GMFCS	Adaptive behavior composite of Vineland-3
F01CP	13;5	White/non-Hispanic	American English	Severe impairment	Yes – mild	91%	Spastic diplegia	II	n/a
F02CP	14;6	White/non-Hispanic	American English	No impairment	No	96%	Spastic hemiplegia	I	n/a
M04CP	11;9	More than one/ non-Hispanic	American English	No impairment	No	93%	Spastic	I	n/a
M08CP	13;8	Asian/non-Hispanic	Mandarin	No impairment[a]	Yes – moderate	70%	Spastic quadriplegia	II	n/a
F01DS	16;1	White/Hispanic-Latine	American English	Severe impairment	Yes – moderate	78%	n/a	n/a	75
F05DS	13;6	White/non-Hispanic	American English	Severe impairment	Yes – moderate	74%	n/a	n/a	67
F07DS	11;9	White/Hispanic-Latine	American English	Severe impairment	Yes – moderate	76%	n/a	n/a	63

Note. Age is provided in years;months; Language impairment classifications are based on the core language score of the Clinical Evaluation of Language Fundamentals–Fifth Edition (Wiig et al., 2013). Intelligibility methodology is reported by Darling-White and Polkowitz (2023). Intelligibility ratings are as follows: high = 81% and up, moderate = 61%–80%, and low = 0%–60% (Natzke et al., 2020). M04CP and F05CP did not report the topographical distribution of their spasticity. CP = cerebral palsy; GMFCS = Gross Motor Function Classification System (Palisano et al., 1997); Vineland-3 = Vineland Adaptive Behavior Scales–Third Edition; F = female; M = male; DS = Down syndrome; n/a = not applicable.

[a]Parent-reported language impairment.

and resampled at 18 kHz, with a low-pass filter at 9 kHz for anti-aliasing using Goldwave.

Speech Task

Participants were asked to read "The Caterpillar" passage (R. Patel et al., 2013) aloud, using a comfortable loudness and pitch. The passage was displayed on a computer monitor approximately 2 ft. away from the participant. "The Caterpillar" passage has a Flesh-Kincaid reading grade level of 5.0. All participants were proficient English speakers and read at a grade level of 5.0 or higher per parent report. Participants were given the opportunity to practice the passage aloud one time prior to data collection. The first author, who collected the data, listened to the practice trial to ensure that each participant could read the passage fluently.

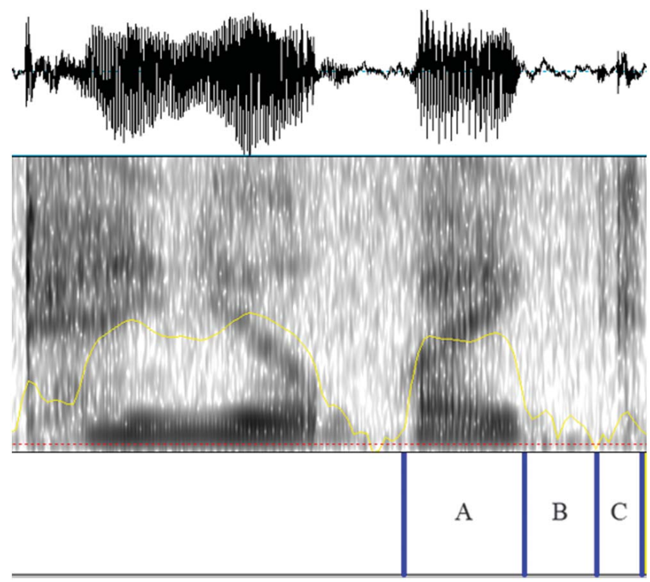
Measurements

The acoustic analyses detailed in this section were performed using Praat (Boersma & Weenink, 2016). Fifty-eight words from "The Caterpillar" passage were identified as having word-final voiced or voiceless stop consonants (excluding nasal consonants; see Appendix A). Both voiced and voiceless word-final stop consonants were included in the analysis as voicing does not significantly impact closure duration (Crystal & House, 1988a, 1988b; Luce & Charles-Luce, 1985). Three durational measurements were hand-measured by the second author for each of the target words (see Figure 1). The durational measurements included the following:

1. Duration of the segment preceding the closure (ms): Defined as the onset of acoustic energy for the first phoneme of the target word to the offset of acoustic energy signaling the beginning of the closure duration for the word-final stop consonant.
2. Closure duration (ms): Defined as a period of silence of any duration preceding the word-final stop consonant. This was measured from the offset of acoustic energy from the duration of the segment preceding the closure to the onset of acoustic energy (i.e., prevoicing or the burst) for the word-final stop consonant. If there was no period of silence, closure duration was given a value of zero.
3. Duration of the segment following the closure (ms): Defined as the onset of the burst for the word-final stop consonant to the offset of acoustic energy associated with aspiration.

Only target words produced fluently and with clearly identifiable bursts (i.e., released stop) associated with the word-final stop consonant were included in the final analyses. Percent pause time was then calculated by

Figure 1. The spectrographic display and text grid of the phrase "Do you like" from "The Caterpillar" passage produced by F05DS. The word "like" contains a word-final stop consonant and was included in our analyses. The letter "A" indicates duration of the segment preceding the closure. The letter "B" indicates the closure duration. The letter "C" indicates the duration of the segment following the closure.



dividing the closure duration (i.e., within-word silent interval) by the duration of the segment preceding and following the closure and multiplying by 100.

Articulation rate (syllables/second) was measured from the entire reading passage to provide a fuller picture of articulatory function of children with neurodevelopmental disorders in our sample. Articulation rate was defined as the time spent producing "The Caterpillar" passage exclusive of pauses divided by the number of syllables. A pause was defined as a between-words silent interval greater than or equal to 150 ms (e.g., Darling-White & Banks, 2021; Darling-White & Jaeger, 2023). A within-word silent interval greater than or equal to 150 ms was only counted as a pause if there was perceptual and acoustic evidence of a breath. This only occurred one time in our sample.

Reliability

Data from three participants (one child with CP, one child with DS, and one TD child) were reanalyzed by a second measurer, the first author. Intermeasurer reliability was evaluated by computing the Cronbach's alpha between the two sets of measurements for each dependent variable. Cronbach's alpha ranged from .95 to 1, indicating high intermeasurer reliability.

Table 2. Number of target words included in acoustic analyses.

Participant	No. of words analyzed
F01CP	17
F02CP	22
M04CP	21
M08CP	56
F01DS	14
F05DS	26
F07DS	25
F10TD	25
M12TD	23
F16TD	25
F17TD	30
M23TD	15
F25TD	19
M32TD	24
F68TD	25

Note. F = female; CP = cerebral palsy; M = male; DS = Down syndrome; TD = typically developing.

Statistical Analysis

Previous work from the first author has demonstrated that children with CP and children with DS can demonstrate different articulation rates (Darling-White & Jaeger, 2023). To ensure it was appropriate to group the children with CP and the children with DS together in the current analyses, articulation rates between these groups were compared using a *t* test. There was no significant difference in articulation rate between children with CP and children with DS, $t(301.63) = -0.42$, $p = .68$, in this sample. For the remaining analyses, children with CP and children with DS were considered as one group, children with neurodevelopmental disorders.

Differences between children with neurodevelopmental disorders and TD children for closure duration, percent pause time, and articulation rate were analyzed using *t* tests with a significance level of $p \leq .05$. The number of closure durations of ≥ 150 ms was examined descriptively.

Results

The number of target words analyzed for each participant is reported in Table 2. Descriptive results (means and standard deviations) for each dependent variable are presented by group in Table 3 and by participant in Table 4. Appendix B presents each closure duration produced by participant.

There was a significant effect of group for each dependent variable: closure duration, $t(229.85) = -4.95$, $p < .001$; percent pause time, $t(325.02) = -2.10$, $p < .04$; and articulation rate, $t(510.21) = 10.47$, $p < .001$. Closure duration and percent pause time were significantly longer for children with neurodevelopmental disorders than for TD children. Articulation rate was significantly slower for children with neurodevelopmental disorders than for TD children.

Children with neurodevelopmental disorders produced closure durations that met or exceeded the minimum duration threshold of a pause (150 ms), but TD children, generally, did not. A total of 15.5% closure durations produced by children with neurodevelopmental disorders (67% of which were produced by children with CP) were ≥ 150 ms and could have been classified as pauses. Every child with a neurodevelopmental disorder produced at least one within-word silent interval of ≥ 150 ms. Only 1.1% of total closure durations produced by TD children were ≥ 150 ms. This amounted to two closure durations, both produced by the same participant (F16TD).

Discussion

The purpose of this preliminary study was to investigate the within-word silent interval associated with the stop closure in word-final stop consonants during a reading passage produced by children with and without neurodevelopmental disorders. This is the first study, to our knowledge, to systematically examine any type of within-word silent intervals produced by children with neurodevelopmental disorders. Results revealed two key findings, both of which supported our initial hypotheses. First, children with neurodevelopmental disorders produced longer closure durations (both in absolute terms and in terms of percentage of time) and slower articulation rates than TD children. The majority of children with neurodevelopmental disorders followed these statistical trends (five of seven for closure duration, six of seven for percent pause time, and five of seven for articulation rate). No pattern was found across measures for the children who did not

Table 3. Group means (standard deviations) for each dependent variable.

Participant	Articulation rate (syll/s)	Closure duration (ms)	Percent pause time (%)
NDD	3.59 (1.37)	80 (100)	13.31 (13.76)
TD	4.67 (0.97)	40 (40)	10.68 (9.82)

Note. syll = syllables; NDD = children with neurodevelopmental disorders; TD = typically developing children.

Table 4. Individual means (standard deviations) for each dependent variable.

Participant	Articulation rate (syll/s)	Closure duration (ms)	Percent pause time (%)
F01CP	3.98 (1.12)	60 (70)	16.26 (16.98)
F02CP	5.42 (1.61)	40 (50)	11.43 (12.81)
M04CP	4.75 (0.89)	60 (140)	12.66 (16.53)
M08CP	2.23 (0.56)	100 (120)	11.05 (11.81)
F01DS	4.15 (0.91)	40 (40)	9.28 (10.91)
F05DS	3.19 (0.93)	90 (70)	19.90 (14.16)
F07DS	3.26 (0.95)	70 (80)	13.96 (13.57)
F10TD	4.58 (0.79)	40 (40)	9.84 (9.03)
M12TD	5.03 (0.71)	30 (40)	8.65 (11.21)
F16TD	3.86 (1)	60 (40)	11.99 (8.30)
F17TD	5.08 (1.05)	30 (30)	8.39 (8.70)
M23TD	4.87 (0.68)	40 (40)	12.61 (11.95)
F25TD	4.48 (0.72)	60 (30)	15.45 (9.01)
M32TD	5.02 (1.18)	20 (20)	7.84 (6.90)
F68TD	4.95 (0.86)	40 (40)	12.75 (12.26)

Note. syll = syllables; F = female; CP = cerebral palsy; M = male; DS = Down syndrome; TD = typically developing.

follow the statistical trend. This is consistent with previous data, which describe children with neurodevelopmental disorders as having increased segmental durations (Lee et al., 2014), slower articulation rate (e.g., Allison & Hustad, 2018; Chapman et al., 1998; DuHadway & Hustad, 2012; Kent et al., 2021; Nip, 2013; White et al., 1994, 1995), and increased pause time (Darling-White et al., 2018; Jones et al., 2019). Second, children with neurodevelopmental disorders consistently produced closure durations that met or exceeded the minimum duration threshold set for the measurement of a pause (150 ms), but TD children, generally, did not. These within-word silent intervals, though long, were the likely product of an articulatory event (i.e., stop closure duration) and not disfluency or cognitive processing issues since only fluent productions of the target words were included in the analyses.

These data indicate the need to examine the location of silent intervals that meet the minimum duration threshold of a pause and correct for articulatory events during the measurement of articulation rate and pauses in children with neurodevelopmental disorders. Within-word silent intervals due to articulatory events are also associated with affricates, and both types of consonants (i.e., stops and affricates) appear in multiple positions within a word (i.e., initial, medial, final). It stands to reason that expanding the examination of within-word silent intervals to include articulatory events across word position will increase the number of within-word silent intervals that meet the minimum duration threshold of a pause in a connected speech sample produced by children with neurodevelopmental disorders. Automated MATLAB programs can still be used for the identification of silent intervals meeting a minimum duration threshold but should now include an additional step in which a research team member examines any potential pauses to determine their location and whether or not they are associated with articulatory events. Otherwise, there is a potential risk of overestimating articulation rate and pauses.

Correcting for articulatory events could be as simple as excluding all within-word silent intervals unless there is kinematic and/or acoustic evidence of a breath (as was done in this study) or as complex as subtracting the average duration of a specific articulatory event from the total duration of the silent interval (Mahr et al., 2021; Redford, 2013). Both methods have inherent flaws. The former relies on the ability of the research team member to appropriately judge whether the within-word silent interval is associated with an articulatory event, which is not always straightforward in a child with speech motor impairment. The latter is only as good as the availability of normative data and could be time-consuming.

At this time, the preliminary data presented in this research note are the only data reporting the duration of stop closures produced by children with neurodevelopmental disorders. Normative data from healthy adult speakers are available but are not the appropriate comparative data set for children with neurodevelopmental disorders. This may be why we could not find any studies involving children with neurodevelopmental disorders that utilized this approach. One study involving TD children used a value of 50 ms in their correction for stop closure durations based on normative data from healthy adult speakers (Mahr et al., 2021). Examining data from our small sample, the 50-ms duration may be appropriate to use for TD children (mean closure duration = 40 ms), but a longer duration is needed for children with neurodevelopmental disorders (mean closure duration = 80 ms). A correction of 80 ms paired with a minimum duration threshold of 150 ms would require a within-word silent interval within the context of a stop consonant to be ≥ 230 ms to be counted as a pause. In our study, this correction would reduce the percentage of within-word silent intervals counted as a pause from 15.5% to 3.9%. Future work should systematically examine the duration of articulatory events produced by children with neurodevelopmental disorders across place of articulation and word position in order to build an appropriate normative database for the correction of articulatory events in the measurement of articulation rate and pauses.

Correcting for articulatory events is preferable, in our opinion, to increasing the minimum duration threshold of a pause because of the variety of communicative events that are associated with silent intervals. Anecdotally, data from our laboratory indicate that children with neurodevelopmental disorders routinely produce breath pauses (i.e., a silent interval in which an inspiration occurs as confirmed by respiratory kinematic signals) around 150 ms. Speech is not produced on inhalation in a majority of languages, so inhalations must be considered pauses. Any threshold that is being used to identify silent intervals should be sensitive enough to identify every (or at least a majority of breath pauses).

Clinical Implications

It is unknown if different methodological approaches for the handling of within-word silent intervals result in statistically or clinically significant differences in articulation rate and pauses. The potential over- or underestimation of articulation rate inherent in some approaches is not likely to diminish their use as a primary indicator of dysarthria, but it could lead to misinterpretation of the factors contributing to speech severity or intelligibility. Without an in-depth analysis of pause location and cause (e.g., physiological need, articulatory event, cognitive processing), creating a treatment plan to target pause patterns is not possible.

Limitations and Future Directions

Given the preliminary nature of this study and the small sample size, children with CP and children with DS were considered as one group. Statistical analyses comparing articulation rate between these groups confirmed that, at least statistically, children with CP and children with DS could be grouped together in this study. However, children with CP and children with DS display different speech motor and cognitive–linguistic profiles, and there may be etiology-specific differences in speech production among these groups (Darling-White & Jaeger, 2023; Darling-White & Polkowitz, 2023). Furthermore, there is a large amount of heterogeneity present within each etiology (e.g., Hustad et al., 2010; Kent et al., 2021). Firm conclusions about the populations of CP and DS cannot be drawn based on three or four children, especially when one of the children in our sample was bilingual or some had documented hearing loss. The purpose of this study was not to draw conclusions about the populations of CP and DS but rather to highlight a particular methodological concern, the appropriate categorization of silent intervals. Future research regarding silent intervals produced by children with neurodevelopmental disorders should seek to recruit a large number of children from both the CP and DS populations, representing a wide variety of speech motor impairment, and examine these groups separately.

In four instances, the target word from "The Caterpillar" passage ended with a stop + fricative (i.e., [ks] or [ts]). Due to the preliminary nature of this study, the authors wanted to include as many word-final stops as possible. It is unclear if the addition of the [s] meaningfully changes the closure duration for the analyzed stop. As stated above, there are many open questions about the durations of articulatory events, such as stop closures, produced by children with neurodevelopmental disorders. Regardless of whether the target word ended with a stop + fricative or just a stop, the main conclusion of the study does not change. Silent intervals produced by children with neurodevelopmental disorders should be examined more closely.

Data Availability Statement

The data supporting the conclusions of this article can be found in the tables and figures. Any further data requests should be made to the first author, Meghan Darling-White.

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Appendix A

"The Caterpillar" Passage With Target Words Marked

Do you like amusement parks? Well, I sure do. To amuse myself, I went twice last spring. My most memorable moment was riding on the Caterpillar, which is a gigantic roller coaster high above the ground. When I saw how high the Caterpillar rose into the bright blue sky I knew it was for me. After waiting in line for thirty minutes, I made it to the front where the man measured my height to see if I was tall enough. I gave the man my coins, asked for change, and jumped on the cart. Tick, tick, tick, the Caterpillar climbed slowly up the tracks. It went so high I could see the parking lot. Boy was I scared! I thought to myself, "There's no turning back now." People were so scared they screamed as we swiftly zoomed fast, fast, and faster along the tracks. As quickly as it started, the Caterpillar came to a stop. Unfortunately, it was time to pack the car and drive home. That night I dreamt of the wild ride on the Caterpillar. Taking a trip to the amusement park and riding on the Caterpillar was my most memorable moment ever!

Note. "The Caterpillar" reprinted from R. Patel et al. (2023).

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Each Closure Duration Produced by Participant

Participant	Closure duration (ms)	Number of instances
F01CP	0	6
	21	1
	30	1
	58	1
	60	1
	74	1
	96	1
	110	1
	149	1
	164[a]	1
	166[a]	1
	176[a]	1
F02CP	0	9
	29	2
	33	1
	45	2
	51	1
	53	1
	58	1
	71	1
	88	1
	143	1
	152[a]	1
	170[a]	1
M04CP	0	8
	30	1
	33	1
	42	1
	43	1
	48	1
	51	1
	59	1
	60	1
	62	1
	65	1
	75	1
	76	1
	667[a]	1

(*table continues*)

Appendix B (p. 2 of 7)

Each Closure Duration Produced by Participant

Participant	Closure duration (ms)	Number of instances
M08CP	0	12
	16	1
	21	1
	22	1
	28	2
	30	1
	31	1
	33	1
	42	1
	46	1
	49	1
	50	1
	52	1
	58	1
	69	1
	72	1
	80	1
	81	1
	83	1
	88	2
	95	2
	96	1
	104	1
	106	1
	114	1
	129	1
	132	1
	133	2
	150[a]	1
	157[a]	1
	191[a]	1
	192[a]	1
	202[a]	1
	207[a]	1
	214[a]	1
	218[a]	1
	222[a]	1
	239[a]	1
	292[a]	1
	394[a]	1
	730[a]	1

(*table continues*)

Appendix B (p. 3 of 7)

Each Closure Duration Produced by Participant

Participant	Closure duration (ms)	Number of instances
F01DS	0	5
	18	1
	19	1
	35	1
	38	1
	59	1
	63	1
	68	1
	87	1
	152[a]	1
F05DS	0	5
	49	1
	56	1
	63	1
	65	1
	70	1
	71	1
	76	1
	79	1
	82	1
	91	1
	115	1
	121	1
	125	1
	126	1
	149	1
	162[a]	1
	169[a]	1
	175[a]	1
	189[a]	1
	224[a]	1
	225[a]	1

(*table continues*)

Appendix B (p. 4 of 7)

Each Closure Duration Produced by Participant

Participant	Closure duration (ms)	Number of instances
F07DS	0	6
	35	1
	43	1
	46	1
	54	1
	55	1
	57	1
	58	1
	61	1
	71	1
	80	1
	84	1
	86	1
	88	1
	106	1
	108	1
	117	1
	136	1
	230[a]	1
	359[a]	1
F10TD	0	8
	12	1
	19	1
	20	1
	30	1
	37	1
	38	1
	44	1
	47	1
	49	1
	56	1
	58	1
	64	1
	65	1
	81	1
	101	1
	127	1
	132	1

(*table continues*)

Appendix B (p. 5 of 7)

Each Closure Duration Produced by Participant

Participant	Closure duration (ms)	Number of instances
F16TD	0	4
	21	1
	27	1
	31	2
	38	1
	44	1
	47	1
	48	1
	54	1
	56	1
	57	1
	67	2
	72	1
	77	1
	79	1
	92	1
	96	1
	115	1
	151[a]	1
	169[a]	1
F17TD	0	14
	23	1
	29	2
	33	1
	41	1
	42	1
	43	1
	45	1
	46	1
	52	1
	56	1
	57	1
	60	2
	91	1
	95	1

(*table continues*)

Appendix B (p. 6 of 7)

Each Closure Duration Produced by Participant

Participant	Closure duration (ms)	Number of instances
F25TD	0	3
	36	1
	46	1
	47	1
	51	1
	53	1
	54	1
	55	1
	59	1
	61	1
	65	1
	66	1
	68	1
	69	1
	91	1
	96	1
	139	1
F68TD	0	9
	20	1
	27	1
	30	1
	31	1
	39	1
	46	2
	47	1
	53	1
	58	1
	84	1
	99	1
	101	1
	107	2
	115	1
M12TD	0	11
	20	1
	22	1
	29	1
	32	1
	33	2
	35	1
	40	1
	69	1
	107	1
	119	1
	126	1

(*table continues*)

Appendix B (p. 7 of 7)

Each Closure Duration Produced by Participant

Participant	Closure duration (ms)	Number of instances
M23TD	0	4
	11	1
	22	1
	28	1
	29	1
	41	1
	54	1
	57	1
	59	1
	79	1
	83	1
	121	1
M32TD	0	7
	15	1
	16	1
	21	1
	22	2
	23	1
	26	1
	29	1
	32	2
	33	2
	39	1
	48	1
	50	1
	55	1
	58	1

Note. F = female; CP = cerebral palsy; M = male; DS = Down syndrome; TD = typically developing.

[a]A closure duration that met or exceeded the minimum duration threshold of a pause (150 ms).