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Research Article

Characteristics of Speech Rate in Children With Cerebral Palsy: A Longitudinal Study

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Purpose: The purpose of this longitudinal study was to examine the effect of time and sentence length on speech rate and its characteristics, articulation rate and pauses, within 2 groups of children with cerebral palsy (CP).
Method: Thirty-four children with CP, 18 with no speech motor involvement and 16 with speech motor involvement, produced sentences of varying lengths at 3 time points that were 1 year apart (mean age = 56 months at first time point). Dependent measures included speech rate, articulation rate, proportion of time spent pausing, and average number and duration of pauses.
Results: There were no significant effects of time. For children with no speech motor involvement, speech rate increased with longer sentences due to increased articulation rate. For children with speech motor involvement, speech rate did not change with sentence length due to significant increases in the proportion of time spent pausing and average number of pauses in longer sentences.
Conclusions: There were no significant age-related differences in speech rate in children with CP regardless of group membership. Sentence length differentially impacted speech rate and its characteristics in both groups of children with CP. This may be due to cognitive–linguistic and/or speech motor control factors.

Cerebral palsy (CP) is a heterogeneous group of disorders primarily characterized by the abnormal development of movement and posture secondary to nonprogressive disturbances in early brain development (Rosenbaum et al., 2007). The majority of recent estimates indicate that over 50% of children with CP are expected to exhibit some sort of speech impairment, with a range of 36%–90% (Cockerill et al., 2014; Hustad, Gorton, & Lee, 2010; Mei, Reilly, Reddihough, Mensah, & Morgan, 2014; Nordberg, Miniscalco, Lohmander, & Himmelmann, 2013; Parkes, Hill, Platt, & Donnelly, 2010). A predominant characteristic of speech impairment in children with CP is slow speech rate (Hodge & Gotzke, 2014a; Hustad et al., 2010; Nip, 2013; Wolfe, 1950; Workinger & Kent, 1991). Slow speech rate in children with CP is a deficit that begins early, with children as young as 3 years of age exhibiting slower than normal speech rates when compared to typical peers (Hodge & Gotzke, 2014a), and persists across the life span (Schölderle, Staiger, Lampe, Strecker, & Ziegler, 2016). Despite the persistence of speech rate deficits, our understanding of the developmental course of speech rate in children with CP is limited.

In typically developing children, speech rate increases with age (e.g., Haselager, Slis, & Rietveld, 1991; Hodge & Gotzke, 2014a; Kent & Forner, 1980; Kowal, O'Connell, & Sabin, 1975; Logan, Byrd, Mazzocchi, & Gillam, 2011; Nip & Green, 2013; Walker, Archibald, Cherniak, & Fish, 1992; Walsh & Smith, 2002; Whiteside, 1999) and is approximately adultlike between 12 and 13 years (Nip & Green, 2013; Walsh & Smith, 2002). By examining the characteristics of speech rate, articulation rate (e.g., the time needed to articulate an utterance), and pauses, it is known that developmental increases in speech rate are the result of both increases in articulation rate (Haselager et al., 1991; Logan et al., 2011; Nip & Green, 2013; Walker et al., 1992; Whiteside, 1999) and decreases in overall pause time (Kowal et al., 1975; Nip & Green, 2013; Whiteside, 1999). Age-related gains in speech rate have been attributed to improved efficiency of both speech motor control and cognitive–linguistic factors (Nip & Green, 2013).

However, to our knowledge, there are no peer-reviewed studies that have examined how speech rate

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and its characteristics change over time during connected speech tasks in children with CP. Given that both speech motor control and cognitive–linguistic skills may be impaired in children with CP, speech rate and its characteristics likely develop differently in children with CP than their typically developing peers (e.g., Cockerill et al., 2014; Hustad et al., 2010; Mei et al., 2014, 2016; Nordberg et al., 2013; Pakula, Van Naarden Braun, & Yeargin-Allsopp, 2009; Parkes et al., 2010). It is important to understand the development of speech rate and its characteristics in children with CP because speech rate is a common target in speech intervention to improve intelligibility in children with CP (Levy, 2014; Pennington, Miller, Robson, & Steen, 2010; Pennington et al., 2013; Pennington, Smallman, & Farrier, 2006) and habitual articulation rate and pausing patterns may significantly impact intervention success. Hustad and Sassano (2002) found that, by training adults with CP (N = 2) to insert pauses between each word of a sentence, the resultant decrease in speech rate resulted in intelligibility gains. However, the extent to which each speaker's intelligibility improved was dependent upon their habitual speech rate characteristics, such that the adult with CP who had the greater gains in intelligibility had a faster habitual speaking rate and very few pauses (Hustad & Sassano, 2002). Speech rate reductions in children with CP could be due to alterations in articulation rate, pause time, or both. Thus, our lack of knowledge about the development of speech rate and its characteristics in children with CP significantly impacts our ability to create speech rate interventions that provide long-term benefits.

In addition, examination of the distribution of speech rate characteristics and how they change over time in children with CP may provide information about the underlying impairment responsible for these traits. For example, children with CP who have more severe respiratory impairment may exhibit more pauses, but children with CP who have more severe articulation impairment may exhibit slower articulation rates. As another example, young children with CP may exhibit deficits in both articulation rate and pauses if several speech subsystems are impacted, but older children may have more specific profiles of deficits (e.g., typical articulation rate but longer, more frequent pauses) as their speech motor control and cognitive–linguistic skills develop. Although it is not the purpose of this study to identify the underlying impairments that contribute to speech rate deficits exhibited by children with CP, these data will provide a starting point for this type of investigation. Currently, intervention strategies targeting speech rate deficits are not tailored to specific deficit profiles and often yield mixed individual results (Pennington et al., 2006, 2010, 2013). Thus, full characterization of speech rate is critical to the development of evidence-based inclusionary and exclusionary criteria for speech rate intervention.

Classification of speech and language deficits exhibited by children with CP within a developmentally sensitive context has been identified as an area of particular importance in the literature (Bax et al., 2005; Rosenbaum et al., 2007). A theoretical framework based on speech and language deficits would allow for the creation of homogenous groups within an inherently heterogeneous population. Researchers would then be able to create and test interventions to improve communication based on specific speech and language profiles potentially improving intervention success. In order to build these types of profile groups, data examining how and to what extent speech and language characteristics develop in children with CP within each potential profile group must be available. Longitudinal studies provide this much needed information and allow researchers to examine the rate and limits of change within a developmentally sensitive context.

The use of longitudinal, as opposed to cross-sectional, methodology when examining the development of speech rate and its characteristics during connected speech may be particularly revealing. Data from cross-sectional studies examining the typical development of speech rate paint the picture that speech rate has a relatively steady developmental trajectory throughout childhood. However, longitudinal studies reveal that typical development of speech rate is protracted and nonlinear (Hall, Amir, & Yairi, 1999; Kubaska & Keating, 1981; Smith & Kenney, 1998, 1999; Walker & Archibald, 2006). Smith and Kenney (1999) stated, "when considering the performance of individual children across intervals of less than several years, periods with no duration or variability changes or periods with reversals are likely to be seen" (p. 98). For example, Walker and Archibald (2006) found that articulation rate did not significantly change from 4 years of age to 6 years of age and actually significantly decreased at 5 years of age. Nip and Green (2013) found nonsignificant decreases in speech rate between 13 and 16 years of age. These periods of protracted development and nonlinear shifts in speech production skills may be even more exaggerated in children with CP given the potential for speech motor and/or cognitive–linguistic deficits.

This longitudinal study sought to begin characterizing speech rate during connected speech within groups of children with CP that exhibit similar speech motor abilities. We utilized the Speech Language Profile Groups framework proposed by Hustad and colleagues (Hustad et al., 2010; Hustad, Oakes, McFadd, & Allison, 2016). This theoretical framework classifies children with CP based on the presence or absence of speech motor impairment and receptive language involvement (Hustad et al., 2010, 2016). Speech motor impairment was defined as "clinically observable evidence of motor impairment in any one or more of the speech subsystems (articulation, phonation, resonation, respiration) that could be observed perceptually" (Hustad et al., 2010, p. 1498). Based on the variables of speech rate, vowel space, language comprehension, and speech intelligibility, children with CP were classified into the following groups with 97.1% accuracy: children with no speech motor involvement (NSMI), children with speech motor involvement (SMI) and typically developing language abilities, children with SMI and impaired language abilities, and children with anarthria. Furthermore, speech rate was of particular importance when distinguishing between children with CP and NSMI and children with CP and SMI (Hustad et al., 2010). It was hypothesized that speech rate contributed to profile group membership more than any other measure, including vowel space and intelligibility, because speech rate is reflective of coordination across multiple speech subsystems and likely represents a broader range of speech deficits exhibited by children with CP (Hustad et al., 2010). However, speech rate did not distinguish between children with CP who demonstrated receptive language impairment and those who did not (Hustad et al., 2010). Therefore, this study focused solely on the characterization of speech rate within groups of children with CP, those with NSMI and those with SMI. Within-group as opposed to between-groups differences were the focus of this paper because researchers must understand the developmental course of speech rate and its characteristics within each profile group in order to create profile-based interventions to improve speech intervention.

During the initial development of the Speech Language Profile Groups framework, speech rate was examined holistically and was not broken into its component parts, articulation rate and pauses. Because age-related changes in speech rate are realized through alterations in articulation rate and pauses (Haselager et al., 1991; Kowal et al., 1975; Logan et al., 2011; Nip & Green, 2013; Walker et al., 1992; Whiteside, 1999), a complete understanding of the developmental course of speech rate in children with CP must include the examination of both of these factors within connected speech tasks. Unfortunately, the available literature falls short in this area. The handful of studies regarding speech rate characteristics in children with CP focus almost exclusively on articulation rate, which is reduced as compared to typically developing peers (Allison & Hustad, 2018; DuHadway & Hustad, 2012; Nip, 2013; White, Craft, Hale, & Park, 1994; White, Craft, Hale, Schatz, & Park, 1995). Nip (2013) is the only peer-reviewed study that has examined articulation rate and pauses during connected speech (i.e., sentence repetition). However, findings from Nip (2013) are somewhat limited as the sample included only four children with CP and sentences were only four words in length.

Examining the characteristics of speech rate during connected speech tasks that include a variety of sentence lengths is vital in order to produce ecologically valid results because speech production in naturalistic contexts involves the use of a variety of sentence lengths. In addition, speech rate is affected by sentence length though the relationship is complicated, and results are mixed as to whether speech rate increases (Haselager et al., 1991), remains the same (Logan et al., 2011; Walker & Archibald, 2006; Walker et al., 1992), or decreases (Sadagopan & Smith, 2008) with increases in sentence length in typically developing children. Regardless of the direction of change, there is reason to believe that speech rate could be altered by sentence length in children with CP. Increases in sentence length likely impose greater cognitive–linguistic demands as evidenced by the significantly larger number of incorrect responses produced by children when imitating sentences of increasing length (Miller, 1973; Montgomery, Montgomery, & Stephens, 1978; Smith & van Kleeck, 1986). There is also a great deal of evidence to support the idea that cognitive–linguistic demands influence speech motor performance in typically developing children (Goffman, 2010). Thus, increases in sentence length likely tax both speech motor control and cognitive–linguistic skills (Maner, Smith, & Grayson, 2000). Given that these factors are known to greatly influence speech rate (Nip & Green, 2013), it is likely that increases in sentence length impact speech rate performance in children with CP. The effects of sentence length may differentially impact children with SMI and those with NSMI.

The purpose of this longitudinal study was to examine the effect of time and sentence length on speech rate and its characteristics, articulation rate and pauses, in children with CP. Using the Speech Language Profile Groups framework proposed by Hustad and colleagues (2010, 2016), we examined these issues within two groups of children with CP, those with NSMI and those with SMI, across a 2-year period. We addressed the following specific research questions:

1. Are there differences in speech rate and its characteristics over time within the two groups of children with CP?
2. Are there differences in speech rate and its characteristics for sentences of different length within the two groups of children with CP?

Method

Participants

Children With CP

Thirty-four children (16 boys, 18 girls) with CP were included in the current longitudinal study. All children were participating in a larger longitudinal study focused on the communication development of children with CP. None of the data reported in this study have been previously published. To participate in the larger study, children were required to (a) have a medical diagnosis of CP and (b) have normal hearing as evidenced by a formal audiological evaluation or distortion product otoacoustic emission screening. Out of the larger cohort, children with CP who completed three sessions at approximately 1-year intervals between the ages of 54 and 83 months and produced at least four-word sentences during those sessions were chosen for inclusion in the current study. The speech task used in this study, which will be described in detail in a later paragraph, required children to repeat sentences up to seven words in length. As we were interested in examining speech rate during connected speech in children with CP, production of at least four-word sentences was required to enhance the ecological validity of our findings. The initial age of this longitudinal study (54 months) was chosen in order to maximize the number of children with CP whose data could be analyzed. This was the age at which the majority of children with CP and SMI could complete the speech task.

Acoustic data (described below) from three separate data collection sessions, henceforth referred to as Time 1, Time 2, and Time 3, were analyzed for the current study.

Sessions were approximately 1 year apart. This interval was chosen to be consistent with longitudinal studies of speech rate in typically developing children of approximately the same age (Hall et al., 1999; Walker & Archibald, 2006). The children with CP were between 54 and 60 months (M = 56.18 months, SD = 1.80 months) at Time 1, 64 and 71 months (M = 67.47 months, SD = 2.11 months) at Time 2, and 76 and 83 months (M = 78.94 months, SD = 1.89 months) at Time 3.

Of the 34 children with CP, 18 had NSMI and 16 had evidence of SMI. The presence or absence of SMI was determined by the first and second authors, both certified speech-language pathologists using standard clinical procedures (Hustad et al., 2010, 2016). These judgments were made during a perceptual assessment of the sentences produced during the Test of Children's Speech (TOCS+; Hodge & Daniels, 2007; described below) from Time 3. In addition, children were examined for the presence or absence of tone in the orofacial musculature, facial symmetry at rest and during movement, as well as the presence of drooling. The second author conducted most of the data collection sessions and was clinically familiar with all children in the sample. Consensus procedures with the first and second author were used to ensure agreement on the classification of each child. Any disagreements were resolved by discussion. Classifications were based on behavioral data from Time 3 because the children with CP were generally more intelligible, which allowed the authors to better distinguish between articulatory distortions due to typical phonological processes versus SMI.

Demographic characteristics of children with CP, including medical diagnosis, gross motor function, language comprehension scores, and intelligibility, are presented by group in Table 1. Because there was little variability across sessions with regard to gross motor function and standardized language comprehension scores, Table 1 reports classifications from Time 3 only. One child with NSMI did not complete language testing at Time 3; therefore, his score from Time 2 was reported.

Gross motor function was obtained using the Gross Motor Function Classification System (GMFCS), a standard clinical measure specifically designed for children with CP (Palisano et al., 2008). The GMFCS stratifies children with CP into one of five levels based on self-initiated gross motor abilities, with an emphasis on sitting and walking. GMFCS Level I indicates little to no gross motor impairment, whereas GMFCS Level V indicates profound gross motor impairment. In general, most of the children in this study were GMFCS Level I or II. The SMI group contained some children with more severe gross motor impairments, with two children at GMFCS Level III and two at GMFCS Level IV. Language comprehension was measured using the Test for Auditory Comprehension of Language–Third Edition (Carrow-Woolfolk, 1999). Language comprehension was considered impaired if the child was more than 1 *SD* below the mean.

One hundred two adult listeners (one listener per session per child) provided orthographic transcriptions of the sentences from the TOCS+ as a basis for intelligibility measures. Listeners were required to (a) pass a pure-tone hearing screening at 25 dB HL for 250, 500, 1000, 4000, and 6000 kHz bilaterally; (b) be 18–45 years of age; (c) have no more than incidental exposure to persons with communication disorders; (d) be a native speaker of American English; and (e) have no speech, language, learning, or cognitive impairment per self-report. Although these listeners were untrained, ratings of speech characteristics produced by individuals with SMI do not significantly differ between trained and untrained listeners (Bunton, Kent, Duffy, Rosenbek, & Kent, 2007; Fonville et al., 2008). Listeners were asked to use a computer to orthographically transcribe all the words that they heard. Speech stimuli were presented via computer speakers in a sound-attenuating suite. Listeners heard each sentence one time and were instructed to take their best guess if they were unsure what the child said. Mean percent intelligibility was calculated by summing the number of words correctly identified, dividing by the total number of words, and multiplying by 100. Because intelligibility ratings served as a descriptive measure and were not included in any statistical comparisons, these data were based on the responses of one listener per session

Table 1. Demographic characteristics of children with cerebral palsy by group.

Demographic variable	NSMI (n = 18)	SMI (n = 16)
Male:female ratio	11:7	5:11
Mean age, months (*SD*)		
Time 1	56 (1.78)	55 (1.84)
Time 2	67 (2.09)	67 (2.11)
Time 3	79 (1.93)	78 (1.82)
Type of CP		
Diplegia	6	3
Hemiplegia (left)	7	3
Hemiplegia (right)	3	3
Triplegia	0	1
Quadriplegia	0	2
Ataxia	1	1
Athetoid	0	1
Hypotonic	0	1
Mixed	0	0
Unknown	1	1
GMFCS		
I	12	5
II	6	7
III	0	2
IV	0	2
V	0	0
Language comprehension		
Typical	15	11
Impaired	3	5
Speech intelligibility (*SD*)		
Time 1	71.69 (21.34)	35.91 (22.97)
Time 2	84.68 (12.29)	53.11 (25.15)
Time 3	89.47 (10.33)	62.23 (26.87)

Note. NSMI = no speech motor involvement; SMI = speech motor involvement; *SD* = standard deviation; CP = cerebral palsy; GMFCS = Gross Motor Function Classification System.

per child. This method is consistent with the manner in which intelligibility is measured by speech-language pathologists in the clinical setting.

Several children from both the NSMI and SMI groups were involved with speech therapy during the course of the study. However, these numbers were not consistent across each time point. It was also difficult to determine if speech rate was a primary target of intervention. The children with NSMI likely did not have speech rate goals as they did not have dysarthria. The children with SMI may or may not have had speech rate goals. We did obtain some of the Individualized Education Programs for the children with SMI that received speech therapy. Several children with SMI did not have goals written for speech production and were being seen solely for receptive language deficits. Goals having to do with speech production were often written so vaguely (e.g., improve speech intelligibility) that it was impossible to know if speech rate was targeted. Thus, it was not possible to tease apart the impact of intervention versus development.

Acquisition of Speech Samples

Children with CP produced single words and sentences taken from the TOCS+ (Hodge & Daniels, 2007) using a repetition paradigm. Children heard a prerecorded adult model via a laptop computer and then produced the stimulus word or sentence. To ensure that children's productions did not overlap with the prerecorded adult model, each production was monitored by a research assistant who asked the children to repeat the stimulus if overlap occurred. The sentences systematically varied from two to seven words in length, with 10 sentences at each sentence length. The same stimuli were utilized at each time point and with each child to ensure equivalence across time and children.

The TOCS+ stimuli are developmentally appropriate (lexically, phonetically, syntactically, and morphologically) for young children. The linguistic characteristics of each sentence fell at or below a 41-month developmental level and were considered within the language abilities of the children in this study (Hustad, Schueler, Schultz, & DuHadway, 2012). The TOCS+ has demonstrated construct-related validity as a tool for obtaining intelligibility and speech rate measures in 3+-year-old children with speech disorders, including speech motor impairment (Hodge & Gotzke, 2014a), and has been widely used to assess the speech of children with CP (e.g., Allison & Hustad, 2018; Hodge & Gotzke, 2010, 2014a, 2014b; Hustad et al., 2010, 2012; Hustad, Oakes, & Allison, 2015; Levy, Chang, Ancelle, & McAuliffe, 2017; Nip, Arias, Morita, & Richardson, 2017). The TOCS+ also has good criterion-related validity for the measurement of speech rate. Hodge and Gotzke (2014b) compared speech rate in imitated sentences (via the TOCS+) and conversation in children with CP and found a relatively strong correlation. When the authors examined sentences of the same length, speech rate in imitated sentences and conversation differed by less than two words per minute.

This was an early task in a larger research protocol that was administered by a speech-language pathologist in a sound-attenuating room. The acoustic signal was captured by a condenser studio microphone (Audio-Technica AT4040) that was positioned approximately 18 in. from the child's mouth. The microphone signal was recorded via a digital audio recorder (Marantz PMD 570) at a 44.1-kHz sampling rate (16-bit quantization). The level of the signal was monitored and adjusted on a mixer (Mackie 1202 VLZ) to obtain optimized recordings and to avoid peak clipping.

Measurements

Analyses for this study were performed on sentences from four to seven words in length for a total of 40 sentences (10 per word length). These sentences were chosen for analysis because pauses are more likely to occur in longer sentences. Children were required to produce at least five out of the 10 sentences at the four-word sentence length to be included in the study. Table 2 reports the number of children with CP who produced each sentence length by group (NSMI, SMI) and time. The first and second author listened to each sentence to determine the number of words and syllables produced. If intelligibility impacted the ability to determine the number of words produced, the number of words and syllables from the target sentence was used. Sentences produced with fewer than four words or more than seven words were discarded. Sentences were not discarded if the child made a lexical error that did not change the length of the sentence (e.g., substituting a two-syllable word for another two-syllable word). However, this rarely occurred. For children with NSMI, 1.62% of the data at Time 1, 0.84% of the data at Time 2, and 0.42% of the data at Time 3 were discarded. For children with SMI, 4.52% of the data at Time 1, 2.19% of the data at Time 2, and 1.13% of the data at Time 3 were discarded.

Acoustic analyses were made in Praat (Boersma & Weenink, 2016). Sentence duration was defined as the time

Table 2. Number of children who produced each sentence length by group and time.

Sentence length	NSMI (n = 18)	SMI (n = 16)
4 words	Time 1: 18	Time 1: 16
	Time 2: 18	Time 2: 16
	Time 3: 18	Time 3: 16
5 words	Time 1: 18	Time 1: 15
	Time 2: 18	Time 2: 15
	Time 3: 18	Time 3: 16
6 words	Time 1: 16	Time 1: 13
	Time 2: 18	Time 2: 15
	Time 3: 18	Time 3: 15
7 words	Time 1: 16	Time 1: 10
	Time 2: 18	Time 2: 15
	Time 3: 18	Time 3: 15

Note. NSMI = no speech motor involvement; SMI = speech motor involvement.

between sentence initiation and termination. Using the spectrographic signal, sentence initiation was identified by the onset of audible or visible acoustic energy associated with production of the first phoneme of the sentence, and sentence termination was identified by the offset of acoustic energy associated with production of the final phoneme of the sentence. Pauses were defined as a period of silence during the sentence that was 0.150 s or longer (Stathopoulos et al., 2014). The length of each pause was measured from the offset of acoustic energy of one speech segment to the onset of acoustic energy of the next speech segment. Sentence and pause durations were measured in seconds.

The dependent variables of interest were as follows:

1. Speech rate (syllables per second): Speech rate was calculated by dividing the number of syllables by the duration of the sentence.
2. Articulation rate (syllables per second): Articulation rate was calculated by dividing the number of syllables by the duration of the sentence excluding the total pause duration.
3. Proportion of time spent pausing: The proportion of time spent pausing was calculated by dividing the total pause duration by the total duration of the sentence. Values closer to one indicate that a sentence contained mostly pauses, whereas values close to zero indicate that a sentence contained very few pauses.
4. Average number of pauses: The average number of pauses was calculated by counting the total number of pauses across sentences and dividing by the total number of sentences.
5. Average duration of pauses (seconds): The average duration of pauses was calculated by adding the pause durations across sentences and dividing by the total number of pauses.

Three different types of pause measures were included as dependent variables in order to fully characterize how children with CP produce pauses during connected speech. The proportion of time spent pausing represented a holistic view of pausing behavior. The average number and duration of pauses can be viewed as the component parts of the proportion measure. It is important to include both average number and duration of pauses because habitual pausing behavior may be indicative of the underlying impairment and may influence intervention success. There is likely a difference between a child who pauses between every word, but each pause is short, and a child who only pauses once, but the pause is lengthy.

Approximately 20% of the data (three children with NSMI, three children with SMI) were randomly chosen to be reanalyzed by a second individual. The measures chosen for reanalysis were sentence duration, pause duration, and number of pauses. These measurements were chosen because they were determined by the measurer and were not the result of calculations derived from other measures. Interrater reliability was analyzed using *t* tests with an alpha level of .05. The mean difference between the first and second set of analyses was < 0.01 for each of the measures. None of the *t* tests indicated significant differences. Therefore, the measurements were reliable.

Statistical Analysis

To answer our research questions, the data from the children with CP were split into two groups, children with NSMI and children with SMI. Research questions of interest focused on (a) differences in speech rate characteristics over time within each group and (b) differences in speech rate characteristics across sentence length within each group.

In order to answer the research questions, we used a general linear mixed-model analysis of variance to analyze the data. The within-subject variables were sentence length and time. This statistical model is recommended for longitudinal studies with uneven numbers across subjects (Cnaan, Laird, & Slasor, 1997). Main effects (length, time, and Length × Time) were considered significant at an alpha level of .01. Using the Bonferroni correction, pairwise comparisons were considered significant at an alpha level of .003.

Results

Effect of Time

Descriptive results (means and standard deviations) for each dependent measure by time are presented by group in Table 3. For both groups of children with CP, descriptive results suggest that all dependent measures, except proportion of time spent pausing, changed from Time 1 to Time 3. Mean data suggest that speech rate and articulation rate increased whereas average duration of pauses and average pause time

Table 3. Means and standard deviations (in parentheses) for groups by time.

Measure	Time 1	Time 2	Time 3
Speech rate (syll/s)			
NSMI	3.08 (0.49)	3.12 (0.33)	3.20 (0.52)
SMI	2.69 (0.63)	2.79 (0.57)	2.79 (0.62)
Articulation rate (syll/s)			
NSMI	3.17 (0.46)	3.19 (0.33)	3.26 (0.49)
SMI	2.91 (0.56)	2.98 (0.46)	2.95 (0.54)
Proportion of time spent pausing			
NSMI	0.04 (0.04)	0.03 (0.03)	0.03 (0.05)
SMI	0.09 (0.08)	0.08 (0.08)	0.07 (0.07)
Average number of pauses			
NSMI	3.13 (3.40)	2.28 (2.08)	2.24 (3.68)
SMI	5.98 (5.04)	5.76 (5.71)	5.87 (5.48)
Average duration of pauses (s)			
NSMI	0.23 (0.14)	0.20 (0.12)	0.19 (0.17)
SMI	0.32 (0.19)	0.29 (0.17)	0.28 (0.14)

Note. syll/s = syllables per second; NSMI = no speech motor involvement; SMI = speech motor involvement; s = seconds.

Table 4. Main effects for sentence length and time.

Measure	Length (df = 3)		Time (df = 2)	
	F	p	F	p
Speech rate (syll/s)				
NSMI	4.17	.008*	1.00	.371
SMI	1.12	.348	0.36	.699
Articulation rate (syll/s)				
NSMI	7.09	< .001*	0.76	.471
SMI	4.38	.007*	0.29	.750
Proportion of time spent pausing				
NSMI	6.15	.001*	2.17	.121
SMI	5.99	.001*	1.00	.372
Average number of pauses				
NSMI	7.17	< .001*	1.79	.174
SMI	5.11	.003*	0.02	.976
Average duration of pauses (s)				
NSMI	8.02	< .001*	1.68	.191
SMI	4.31	.008*	1.12	.332

Note. syll/s = syllables per second; NSMI = no speech motor involvement; SMI = speech motor involvement; s = seconds.
*p < .01.

decreased. Inferential statistical results for each dependent measure are presented by group in Table 4.

Children With NSMI

Inferential statistics indicated that there were no significant effects of time for any of the rate variables, indicating that speech rate and its characteristics did not significantly change with time for children with NSMI between the ages of 54 and 83 months.

Children With SMI

Inferential statistics indicated that there were no significant effects of time for any of the rate variables, indicating that speech rate and its characteristics did not significantly change with time for children with SMI between the ages of 54 and 83 months.

Effect of Sentence Length

Descriptive results (means and standard deviations) for each dependent measure by sentence length are presented by group in Table 5. For both groups of children with CP, descriptive results suggest that all dependent measures increased with sentence length (i.e., speech was faster and pauses were longer and more frequent), particularly from four-word sentences to six- and seven-word sentences. Inferential results for each dependent measure are presented by group in Table 4. Pairwise comparisons for sentence length differences are presented by group in Table 6. Figure 1 depicts speech rate by sentence length for each group. Figure 2 depicts articulation rate by sentence length for each group. Figure 3 depicts the proportion of time spent pausing by sentence length for each group.

Table 5. Means and standard deviations (in parentheses) for groups by sentence length.

Measure	4 words	5 words	6 words	7 words
Speech rate (syll/s)				
NSMI	2.96 (0.39)	3.17 (0.47)	3.22 (0.45)	3.17 (0.44)
SMI	2.63 (0.51)	2.76 (0.53)	2.84 (0.72)	2.80 (0.66)
Articulation rate (syll/s)				
NSMI	3.00 (0.38)	3.22 (0.44)	3.32 (0.42)	3.30 (0.41)
SMI	2.74 (0.45)	2.92 (0.45)	3.04 (0.60)	3.09 (0.53)
Proportion of time spent pausing				
NSMI	0.02 (0.03)	0.02 (0.03)	0.04 (0.05)	0.05 (0.05)
SMI	0.05 (0.06)	0.07 (0.06)	0.08 (0.09)	0.12 (0.08)
Average number of pauses				
NSMI	1.56 (2.51)	1.63 (1.96)	3.26 (3.67)	3.75 (3.58)
SMI	3.73 (4.21)	5.93 (5.01)	5.93 (5.67)	7.90 (6.03)
Average duration of pauses (s)				
NSMI	0.18 (0.12)	0.15 (0.14)	0.22 (0.13)	0.28 (0.16)
SMI	0.24 (0.14)	0.28 (0.16)	0.32 (0.19)	0.35 (0.16)

Note. syll/s = syllables per second; NSMI = no speech motor involvement; SMI = speech motor involvement; s = seconds.

Table 6. Pairwise comparisons for sentence length by group.

Measure	Contrast	Mean difference	*SE*	*p*
Speech rate (syll/s)	NSMI			
	4 words vs. 5 words	−0.21	0.08	.091
	4 words vs. 6 words	−0.27	0.08	.015
	4 words vs. 7 words	−0.212	0.09	.09
	5 words vs. 6 words	−0.05	0.09	1
	5 words vs. 7 words	< −0.01	0.09	1
	6 words vs. 7 words	0.05	0.09	1
	SMI			
	4 words vs. 5 words	−0.13	0.11	1
	4 words vs. 6 words	−0.21	0.13	.704
	4 words vs. 7 words	−0.17	0.13	1
	5 words vs. 6 words	−0.08	0.14	1
	5 words vs. 7 words	−0.04	0.13	1
	6 words vs. 7 words	0.04	0.15	1
Articulation rate (syll/s)	NSMI			
	4 words vs. 5 words	−0.21	0.08	.063
	4 words vs. 6 words	−0.32	0.08	.001*
	4 words vs. 7 words	−0.30	0.08	.001*
	5 words vs. 6 words	−0.11	0.09	1
	5 words vs. 7 words	−0.09	0.08	1
	6 words vs. 7 words	0.02	0.08	1
	SMI			
	4 words vs. 5 words	−0.19	0.09	.313
	4 words vs. 6 words	−0.30	0.11	.06
	4 words vs. 7 words	−0.35	0.11	.011
	5 words vs. 6 words	−0.12	0.11	1
	5 words vs. 7 words	−0.17	0.11	.814
	6 words vs. 7 words	−0.05	0.13	1
Proportion of time spent pausing (s)	NSMI			
	4 words vs. 5 words	< 0.01	0.01	1
	4 words vs. 6 words	−0.02	0.01	.294
	4 words vs. 7 words	−0.03	0.01	.003*
	5 words vs. 6 words	−0.02	0.01	.211
	5 words vs. 7 words	−0.03	0.01	.002*
	6 words vs. 7 words	−0.02	0.01	.705
	SMI			
	4 words vs. 5 words	−0.02	0.01	.939
	4 words vs. 6 words	−0.03	0.02	.373
	4 words vs. 7 words	−0.06	0.02	.001*
	5 words vs. 6 words	−0.01	0.02	1
	5 words vs. 7 words	−0.05	0.02	.03
	6 words vs. 7 words	−0.03	0.02	.517
Average number of pauses	NSMI			
	4 words vs. 5 words	−0.07	0.42	1
	4 words vs. 6 words	−1.71	0.61	.043
	4 words vs. 7 words	−2.19	0.6	.004
	5 words vs. 6 words	−1.63	0.58	.04
	5 words vs. 7 words	−2.12	0.57	.003*
	6 words vs. 7 words	−0.49	0.72	1
	SMI			
	4 words vs. 5 words	−2.20	0.97	.158
	4 words vs. 6 words	−2.20	1.07	.255
	4 words vs. 7 words	−4.17	1.12	.002*
	5 words vs. 6 words	0	1.15	1
	5 words vs. 7 words	−1.97	1.2	.626
	6 words vs. 7 words	−1.97	1.27	.759

(*table continues*)

Table 6. *(Continued).*

Measure	Contrast	Mean difference	*SE*	*p*
Average duration of pauses (s)	NSMI			
	4 words vs. 5 words	0.02	0.02	1
	4 words vs. 6 words	–0.04	0.02	.514
	4 words vs. 7 words	–0.11	0.03	.001*
	5 words vs. 6 words	–0.07	0.03	.088
	5 words vs. 7 words	–0.13	0.03	< .001*
	6 words vs. 7 words	–0.06	0.03	.161
	SMI			
	4 words vs. 5 words	–0.04	0.03	1
	4 words vs. 6 words	–0.08	0.04	.188
	4 words vs. 7 words	–0.11	0.03	.007
	5 words vs. 6 words	–0.05	0.04	1
	5 words vs. 7 words	–0.07	0.03	.232
	6 words vs. 7 words	–0.03	0.04	1

Note. *SE* = standard error; syll/s = syllables per second; NSMI = no speech motor involvement; SMI = speech motor involvement; s = seconds.
*$p \leq .003$.

Children With NSMI

Inferential results indicated there was a significant effect of sentence length for each dependent variable for children with NSMI. However, there were no significant pairwise differences for speech rate. Articulation rate significantly increased from four-word sentences to six- and seven-word sentences. The proportion of time spent pausing and average duration of pauses significantly increased from four- and five-word sentences to seven-word sentences. The average number of pauses significantly increased from five-word sentences to seven-word sentences.

Children With SMI

Inferential results indicated that there was a significant effect of sentence length for articulation rate, proportion of time spent pausing, average number of pauses, and average duration of pauses for children with SMI. There were no significant effects of sentence length for speech rate for children with SMI. There were no significant pairwise differences for articulation rate. The proportion of time spent pausing significantly increased from four- and five-word sentences to seven-word sentences. Average number of pauses significantly increased from four-word sentences to seven-word sentences. There were no significant pairwise differences for average duration of pauses.

Discussion

This longitudinal study sought to examine the effect of time and sentence length on speech rate and its characteristics, articulation rate and pauses, during connected speech within the two groups of children with CP, those with NSMI and those with SMI. Given the lack of previously published data regarding speech rate and its characteristics in children with CP, this study provides a foundation with which to address important clinical questions, such as how

Figure 1. Speech rate by sentence length (NSMI = no speech motor involvement; SMI = speech motor involvement).

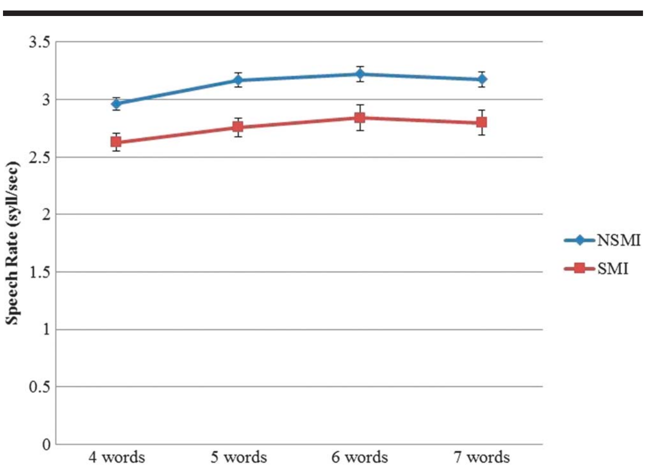


Figure 2. Articulation rate by sentence length (NSMI = no speech motor involvement; SMI = speech motor involvement.

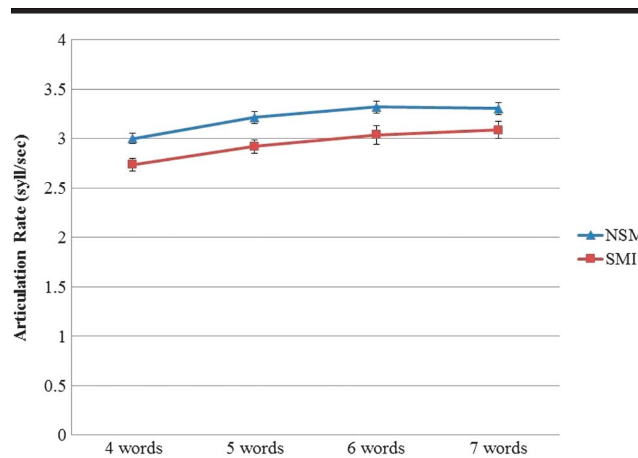
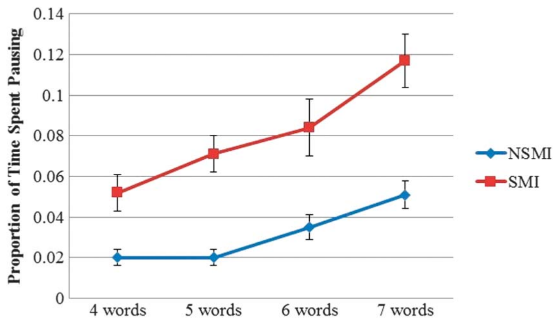


Figure 3. Proportion of time spent pausing by sentence length (NSMI = no speech motor involvement; SMI = speech motor involvement).



underlying impairments in cognitive–linguistic and speech motor control impact speech rate in children with CP. Results revealed two key findings that will be discussed in detail below. First, time (development over 2 years) did not significantly impact speech rate or its characteristics in children with CP, regardless of group membership. Second, sentence length significantly impacted speech rate and/or its characteristics in both groups of children with CP.

Effect of Time

Longitudinal studies involving children with CP are scarce, making it difficult to compare our results to the existing literature. Lee and Hustad (2013) examined word duration in children with CP, both with SMI and NSMI, across an 18-month period starting at 4 years of age. Results indicated that word duration did not significantly change, regardless of profile group membership, from 4 years of age to approximately 5.5 years of age (Lee & Hustad, 2013). Although it is unclear how word duration and speech rate during connected speech tasks relate to one another, our data and the existing literature converge around the finding that durational measures remain relatively stable between the ages of 4.5 and 6.5 years in children with CP.

Speech rate increases over time in typically developing children from early childhood to adolescence and adulthood (e.g., Haselager et al., 1991; Hodge & Gotzke, 2014a; Kent & Forner, 1980; Kowal et al., 1975; Logan et al., 2011; Nip & Green, 2013; Walker et al., 1992; Walsh & Smith, 2002; Whiteside, 1999). Given that neither group of children with CP demonstrated increases in speech rate across the 2-year time period of this study, it would be easy to assume that the diagnosis of CP itself may be responsible for this finding. However, the majority of studies examining typical speech rate development have been cross-sectional rather than longitudinal and have examined speech rate changes across larger age ranges. Longitudinal studies of typically developing children reveal that speech rate often remains the same and may even decrease across a period of several years (Hall et al., 1999; Kubaska & Keating, 1981; Smith & Kenney, 1998, 1999; Walker & Archibald, 2006). Walker and Archibald (2006) is the only longitudinal study, to our knowledge, that examined similar variables in connected speech tasks in typically developing children that were approximately the same age as the children with CP in our study. Walker and Archibald (2006) found that articulation rate did not significantly change from 4 years of age to 6 years of age and actually significantly decreased at 5 years of age. Given that our data are consistent with the longitudinal data from typically developing children, the stable speech rate in children with CP between the ages of 4.5 and 6.5 years of age may be developmentally appropriate.

Between the ages of 4.5 and 6.5 years, children typically experience rapid growth in communication skills, from improvements in vocabulary to more precise speech sound production, due to refinement in speech motor control and cognitive–linguistic skills. These developmental changes often contribute to increases in intelligibility. Our descriptive data, shown in Table 1, indicate that both groups of children with CP had large changes in intelligibility during the study period. Children with NSMI demonstrated an 18% improvement in intelligibility from Time 1 to Time 3, and children with SMI demonstrated a 26% improvement in intelligibility from Time 1 to Time 3. The relatively stable speech rate observed in children between the ages of 4.5 and 6.5 years may be a compensatory strategy to maintain or improve intelligibility during a time of rapid growth and development. Future studies should examine the developmental course of speech rate and its characteristics during periods of large intelligibility change and during periods of small intelligibility change to further investigate this hypothesis.

Effect of Sentence Length

Sentence length differentially impacted speech rate and its characteristics in children with NSMI and children with SMI. Both groups of children with CP increased articulation rate while producing longer sentences. However, only children with NSMI had significant increases in speech rate as a result. This was likely due to differences in pausing characteristics. Both groups of children with CP paused for a significantly greater proportion of time in longer sentences, but children with SMI did this to a much larger extent based on mean data, potentially negating the effect of increased articulation rate on overall speech rate. This finding is consistent with previous literature. As discussed earlier, longer sentences likely tax both cognitive–linguistic and speech motor skills (Maner et al., 2000). Children and adults spend more time pausing during speaking tasks that are more cognitively and linguistically demanding (Greene, 1984; Greene & Cappella, 1986; Mitchell, Hoit, & Watson, 1996; Nip & Green, 2013). Although the task in this study was a repetition task and required little language formulation, longer sentences may have been more cognitively taxing to remember than shorter sentences. In addition, speakers with speech motor impairment pause more frequently than individuals with no speech motor impairment (Bunton, 2005; Hammen, Yorkston, & Minifie, 1994; Huber, Darling, Francis, & Zhang, 2012; Wang, Kent, Duffy, & Thomas, 2005). This could be due to difficulty coordinating language and respiratory support for speech (Huber & Darling, 2011).

Although our finding that articulation rate increased during longer sentences for both groups of children with CP is consistent with one previous study (Haselager et al., 1991), the majority of the literature has not found a relationship between articulation rate and sentence length (Logan et al., 2011; Walker & Archibald, 2006; Walker et al., 1992). There are several differences between previous work and the current study that could contribute to these findings. The current study is the only published study in which sentence length was systematically varied. Previous studies examined articulation rate within spontaneous speech samples. Because it is unknown how many sentences of each length were included in these samples, it is possible that there was not enough variety to properly examine the difference between shorter and longer sentences. Spontaneous speech tasks also have higher language formulation demands than a repetition task. Children in our study produced each sentence following an adult model. Based on *t* tests, there were no statistically significant differences in articulation rate across different sentence lengths in the adult model. However, descriptive data indicate a slight trend toward increased articulation rate with longer sentences, which may have influenced participant behavior. Finally, this finding could be related to differences in speech motor control. The increase in articulation rate in both groups of children with CP may have been a compensatory strategy for children with CP to maintain speech rate despite the significant increases in the proportion of time spent pausing in longer sentences.

Limitations and Future Directions

There are several limitations to this study that need to be addressed. This study provides a foundation with which to continue the investigation of the developmental course of speech rate in children with CP. However, the 2-year time period of this project was not sufficiently long enough to observe significant changes in speech rate for either group of children with CP. This result could have been due to the relatively short window of time and/or the relatively small number of children with CP in each group. In order to develop a more complete developmental course of speech rate, future work should include a larger number of children with CP over a longer time.

Another limitation is the lack of longitudinal data from typically developing children. Without such data, it is difficult to fully place the performance of children with CP within a developmental context. It is also difficult to predict how and when age-related changes in speech rate may occur in children with CP. Longitudinal studies focused on the typical development of speech rate over longer periods of time are greatly needed.

Given the importance of cognitive–linguistic factors in the development of speech rate and its characteristics, future studies should also examine the relationship between language skills and speech rate in a more systematic manner. This study did test language comprehension, but there were not enough participants with languague comprehension deficits in each group (three NSMI, five SMI) to draw conclusions about the role of language skills in the development of speech rate in children with CP. Future studies should aim to include measures of both expressive and receptive language skills as well as equal numbers of children with CP with and without language deficits. In addition, future studies should measure speech rate in a variety of speech tasks, not just sentence repetition. Measuring speech rate and its characteristics in a variety of speech tasks would allow researchers to examine how language formulation demands impact speech rate and its characteristics. The use of speech tasks other than sentence repetition would also eliminate the potential interference of an adult model. We used a sentence repetition task, the TOCS+, in which children produced sentences of varying lengths following an adult model. This adult model could have interfered with the habitual rate typically chosen by participants.

Clinical Implications

Theoretical frameworks, such as the Speech Language Profile Groups framework, allow researchers to reduce the heterogeneity inherent in children with CP by creating groups based on similar speech and language deficits. This paper provides preliminary data necessary to fully characterize the profile groups, particularly children with CP and NSMI and children with CP and SMI, outlined in the Speech Language Profile Groups framework. Full characterization of these profile groups will allow researchers to design specific inclusionary and exclusionary criteria for interventions designed to enhance intelligibility. Given that the success of interventions designed to target speech rate as a way to improve intelligibility may be dependent upon habitual speech and pausing patterns, these data also provide the necessary information about those habitual patterns that will allow researchers to design interventions that provide long-term benefits.

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