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INVITED ARTICLE

Impact of sentence length and phonetic complexity on intelligibility of 5-year-old children with cerebral palsy

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Abstract
Reduced speech intelligibility is a barrier to effective communication for many children with cerebral palsy (CP). Many variables may impact intelligibility, yet little research attention has sought to quantify these variables. This study examined the influence of sentence characteristics on intelligibility in two groups of children with CP (those with and without dysarthria) and typically-developing children. Questions addressed effects of sentence length on transcription intelligibility among groups; effects of phonetic complexity on intelligibility; and differences in the relationship between sentence characteristics and intelligibility across individual children with dysarthria. Speech samples varying in length from 2–7 words were elicited from 16 children with CP (mean age 59.6 months) and eight typically-developing children (mean age = 59.8 months). One hundred and nineteen naïve listeners made orthographic transcriptions of the children's sentence productions. Sentence length and phonetic complexity affected intelligibility for all groups of children, but had a greater impact on intelligibility for children with dysarthria than those without speech motor impairment. Variable relationships between sentence characteristics and intelligibility were found across individual children with dysarthria. Results suggest that reducing both the length and phonetic complexity of utterances may enhance intelligibility for children with dysarthria. However, there may be important individual differences in the impact of one or both types of sentence characteristics. This highlights the importance of considering individual speech motor profiles when deciding on treatment strategies.

Keywords: *Cerebral palsy, dysarthria, speech development, speech intelligibility.*

Introduction

Children with cerebral palsy frequently have dysarthria (Rosenbaum, 2007), and subsequently experience reduced speech intelligibility (Darley, Aronson, & Brown, 1969a). In turn, reduced speech intelligibility has negative consequences for participation in functional contexts (Pennington & McConachie, 2001). Improving intelligibility is a key goal of speech therapy.

In children, acquisition of intelligible speech is a developmental process. However, little research attention has been given to systematic quantification of speech intelligibility benchmarks in young children. A few studies employing varying methodologies for measuring intelligibility have found that, by age 4, typically-developing children are at least 90% intelligible (Coplan & Gleason, 1988; Flipsen, 2006; Hustad, Schueler, Schultz, & DuHadway, 2012). Intelligibility can be influenced by a variety of factors, including variables related to speech production on behalf of the child, variables related to perception on behalf of the listener, and interactions between perception and production. Extant studies suggest that linguistic context (i.e., single words, sentences, narrative) has an impact on intelligibility. In particular, increased linguistic context (viasentences or spontaneous conversation/narrative) generally leads to better intelligibility than single word productions for adults (Hustad, 2007; Yorkston & Beukelman, 1981). However, the relationship between sentence length and intelligibility in children appears to be more complicated. In a recent study, Hustad et al. (2012) examined word and sentence intelligibility in 4-year-old children with cerebral palsy (both with and without speech motor impairment) compared to typically-developingchildren of the same age. Results of this study showed that, for typically-developing children and children with CP but no speech motor impairment, transcription intelligibility peaked at 4-word utterances, and then decreased slightly at longer sentence lengths. Despite similar trends, overall intelligibility of children with CP without speech motor impairment was lower than for their

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typically-developing peers, suggesting possible sub-clinical speech motor involvement in this group. For children with CP and speech motor impairment, the relationship between sentence length and intelligibility generally showed a decreasing trend, with longer sentences being less intelligible than shorter sentences. The study's findings suggested that the additional linguistic context of longer utterances may not provide the same benefit to intelligibility for children with speech motor involvement as for adults with dysarthria.

In addition to sentence length, the phonetic characteristics of words and sentences may also have an impact on intelligibility. Studies examining speech sound error patterns in adult speakers with cerebral palsy have shown that high-complexity speech sounds requiring refined speech motor control are more commonly misarticulated than lower complexity sounds. For example, several studies have reported that adults with dysarthria secondary to CP more frequently produce fricatives and affricates in error than speech sounds in other categories (Ansel & Kent, 1992; Platt, Andrews, & Howie, 1980).

Children acquire and master speech sounds in a developmental sequence. While speech sound acquisition is often conceptualized in terms of phonological development, the complexity of motor demands for producing speech sounds is closely related to order of acquisition. Kent (1992) examined data from several studies regarding age of speech sound mastery with respect to the complexity of underlying motor movements needed to produce them (Kent, 1992). The author's analyses showed that, across studies, earlier acquired sounds involve more basic regulation of velopharyngeal valving, voicing distinctions, and rate of lingual movement (ballistic vs ramp movements). Sounds acquired later in development, including most fricatives and liquids, require more refined adjustments of lingual position and fine force control. A recent study employing the phonetic complexity principles described in Kent (1992) further confirmed that target consonants with high complexity were more commonly misarticulated by adults with CP and dysarthria, but the way in which sounds were produced differed based on the severity of the individual's intelligibility deficit (Kim, Martin, Hasegawa-Johnson, & Perlman, 2010). As these more complex sounds are later acquired (typically mastered around or after age 6), it stands to reason that young children's intelligibility may be affected by the frequency of high complexity speech sounds in their utterances. Furthermore, children with dysarthria who are developing their speech sound repertoire in the context of a speech motor impairment may have even more difficulty producing utterances with higher phonetic complexity, as both developmental factors and speech motor impairment may affect production of higher complexity sounds.

Together, these studies suggest that, for children with dysarthria, linguistic and phonetic complexity of utterances may affect intelligibility. Longer sentence length and higher phonetic complexity both increase the required speech motor demands of producing an utterance and can lead to reduced intelligibility. However, the relative contribution of these factors to intelligibility does not appear to have been examined in children with dysarthria. Understanding the relationship between sentence characteristics and intelligibility has important clinical implications, as it could potentially inform strategies for maximizing intelligibility for children with dysarthria.

In the present study, the goal was to examine the impact of sentence length and phonetic complexity on intelligibility, as measured by orthographic transcription via naïve listeners. Our specific questions were as follows: (1) Are there differences in transcription intelligibility for sentences varying in length for 5 year old children? Based on a previous study of 4-year-old children, we hypothesized that typically-developing children and those with CP without dysarthria would show stable or increasing intelligibility up to sentences that were 4–5 words in length, but that intelligibility at the longest sentence lengths would be reduced; and children with CP and dysarthria would show gradually decreasing intelligibility as sentence length increased. (2) Are there differences in transcription intelligibility based on phonetic complexity of words in the sentences? As children would not yet be expected to have mastered later developing sounds at age 5, we hypothesized that intelligibility would decrease for all groups of children at higher complexity levels, but increased complexity would have the greatest effect on intelligibility for children with dysarthria. (3) For children with dysarthria, what is the relative contribution of length and phonetic complexity to transcription intelligibility and how do individual children differ with regard to these contributions? Given the wide variation in manifestations of dysarthria among children due to differences in severity and neuropathology, we hypothesized that sentence characteristics would have different relationships to intelligibility across individuals.

Method

Participants

Children with cerebral palsy. Sixteen children with CP participated as speakers. All children were participants in a longitudinal study on communication development in children with CP. Inclusion criteria required that children: (1) have a medical diagnosis of CP; (2) have hearing abilities within normal limits as documented by either formal audiological evaluation or distortion product otoacoustic emission screening; (3) be able to produce 6-word sentences in a repetition format; and (4) be between the ages of 54–66 months.

Half of the children with CP in this study ($n = 8$) had clinical evidence of dysarthria (speech motor impairment (SMI) group). Two speech-language pathologists with extensive experience working with children who have dysarthria judged the presence of dysarthria based on clinically-accepted perceptual criteria (Darley, Aronson, & Brown, 1969b; Workinger & Kent, 1991). The other half of the children with CP had speech production abilities that were within age-appropriate limits (no speech motor impairment (NSMI) group). The mean age of the children in the SMI group was 60.3 months (SD = 3.0). The sample comprised two boys (mean age = 61.6 months; SD = 2.2) and six girls (mean age = 59.8 months; SD = 3.3). The mean age of the children in the NSMI group was 58.9 months (SD = 3.7). The sample comprised five boys (mean age = 59.5 months; SD = 3.9) and three girls (mean age = 57.9 months; SD = 3.9). Table I presents demographic characteristics of children with CP, including medical diagnoses and Gross Motor Function Classification System (GMFCS) level (Palisano, Rosenbaum, Walter, Russell, Wood, & Galuppi, 1997).

Typically-developing children. Eight typically-developing children also participated as speakers (TD group). Inclusion criteria required that children: (1) have typically-developing speech; (2) have typically-developing language; (3) have no history of developmental delay per parent report; and (4) have hearing abilities within normal limits as documented by either formal audiological evaluation or distortion product otoacoustic emission screening.

Table I. Demographics of children with Cerebral Palsy (CP).

	Group SMI ($n = 8$)	Group NSMI ($n = 8$)	Group TD ($n = 8$)
Mean age (SD)	60.3 (3.0)	58.9 (3.7)	59.8 (3.5)
Male:female ratio	2:6	5:3	4:4
Type of CP			
Diplegia	3	3	NA
Hemiplegia	2	4	NA
Quadriplegia	2	0	NA
Athetoid	1	0	NA
Ataxia	0	0	NA
Mixed	0	0	NA
Unknown	0	1	NA
GMFCS level			
Level I	0	4	NA
Level II	2	4	NA
Level III	3	0	NA
Level IV	3	0	NA
Level V	0	0	NA

GMFCS, Gross Motor Classification System; SMI, speech motor impairment; NSMI, no speech motor impairment; TD, typically-developing.

Standardized speech and language screening measures and audiologic screening were administered to ensure that children met inclusion criteria. Speech was screened using the Arizona Articulatory Proficiency Scale-3 (AAPS) (Fudala, 2001). Language was screened using the Preschool Language Scale-4 Screening Test (PLS-4 Screener). All children in this group earned standard scores above 85 on the AAPS and passed the PLS-4 Screener with no more than one incorrect response. The mean age of typically-developing children who were included in the study was 59.8 months (SD = 3.5). The sample comprised four boys (mean age = 60.0 months; SD = 3.9) and four girls (mean age = 59.6 months; SD = 3.6).

Non-disabled adult listeners. One-hundred and nineteen non-disabled individuals participated as listeners. Listeners were recruited from the university community via public postings and were primarily undergraduate students. Five different listeners were randomly assigned to each child (with the exception of one child who had only four listeners); each listener heard only one child producing all stimulus material. Inclusion criteria required that listeners: (1) pass pure tone hearing screening at 25 dB HL for 250 Hz, 500 Hz, 1 kHz, 4 kHz, and 6 kHz bilaterally; (2) be between 18–45 years of age; (3) have no more than incidental experience listening to or communicating with persons having communication disorders; (4) be a native speaker of American English; and (5) have no self-identified language, learning, or cognitive disabilities. Participants were 32 males and 87 females. The mean age of listeners was 22.7 years (SD = 3.3).

Acquisition of speech samples

Children were audio-recorded while repeating a list of single words and sentences from the TOCS+ (Hodge & Daniels, 2007). The present study is based on analysis of children's productions of sentences from 2–7 words in length. Children repeated 10 sentences of each stimulus length following a pre-recorded adult model. Children's productions were monitored on-line by a research assistant to ensure that children's productions did not overlap with the recorded examples. Children were asked to repeat utterances when this criterion was not met. All but two children were able to produce sentences of all lengths. One child in the SMI group and one TD child were not able to repeat the 7-word sentences, but accurately repeated sentences up to six words in length. On a few instances, children made lexical errors in repeating sentences. Sentences were eliminated from analysis if the child added or omitted a word from a sentence or if their production was grammatically incorrect. The proportion of utterances produced by children in each group that were included in analyses are as follows: 94% for the SMI group, 97% for the NSMI group, and 99.5% for the TD group.

The research protocol was administered by a speech-language pathologist in a sound-attenuating room. Speech samples from children were recorded using a digital audio recorder (Marantz PMD 570) at a 44.1 kHz sampling rate (16-bit quantization). A condenser studio microphone (Audio-Technica AT4040) was positioned next to each child using a floor stand, and was located ~18 inches from the child's mouth. The level of the signal was monitored and adjusted on a mixer (Mackie 1202 VLZ) to obtain optimized recordings and to avoid peak clipping.

Acquisition of intelligibility data

Digital audio recordings were transferred to a personal computer and were edited to create individual files for each stimulus utterance produced by each child. Audio samples were peak amplitude normalized (using Sony Sound Forge, version 10.0) to assure that maximum loudness levels of the recorded speech samples were the same across children and utterances, while preserving the amplitude contours of the original productions.

Listeners were presented with speech stimuli, delivered via in-house software, and then asked to transcribe orthographically what they thought the child had said. Individual stimulus sentences produced by each child were randomized across utterance lengths for each listener so that no two listeners heard the stimulus items in the same sequence. During the experiment, listeners were seated individually in a sound attenuating suite in front of a 19-inch flat panel computer screen with a keyboard placed directly in front of them. An external speaker was connected to a computer and situated adjacent to the computer screen. The peak audio output level was calibrated to ~75 dB SPL from where listeners were seated and was checked periodically to ensure that all listeners heard stimuli at the same output level.

Listeners were allowed to hear each utterance one time. They were told that the purpose of the study was to determine how understandable children were to unfamiliar listeners like themselves. They were instructed that children would be producing real words and to take their best guess if they were unsure as to what the child said. Listeners were provided with instructions on how to use the experimental software to advance through the experiment. In addition, they heard two sample utterances to familiarize themselves with the experimental task. Data from the sample utterances were excluded from analyses.

Dependent measures

Intelligibility by sentence length. Orthographic transcriptions of children were scored using our in-house software. The software automatically tallied the number of transcribed words that were an exact phonemic match to the stimulus words in the sentences produced by the children. Mis-spellings and homonyms were accepted as correct, as long as all *phonemes* in the spoken version of the transcribed words matched the target words. The number of words identified correctly for each individual listener of each child was summed and divided by the number of words possible for each sentence by stimulus length condition. Sentence length was used as an independent variable to examine difference in intelligibility scores based on number of words per utterance.

Intelligibility by word-level phonetic complexity. Phonetic complexity was calculated using the consonant classification system described by Kim et al. (2010). This system uses principles of speech motor complexity described by Kent (1992) to assign consonants into four levels of articulatory complexity. Level 1 consonants (/p, m, n, w, and h/) require the least complex articulatory movements and are produced in bilablial, alveolar, or glottal positions. Level 2 consonants (/b, d, k, g, j, f/) include velar place of articulation and increasingly complex tongue and lip movements. Level 3 consonants (/t, ŋ, r, l/) include tongue bending configurations, and level 4 consonants (/s, z, ʃ, v, θ, ð, ʧ, ʤ/) require the most fine force regulation of the tongue for frication across places of articulation. As the system used by Kim et al. (2010) only accounts for singleton consonants, an additional level was added to this scoring system to account for consonant clusters present in stimulus sentences. All consonant clusters were assigned a complexity level of 5. For the present study, all stimulus sentences were phonetically transcribed. Each consonant was assigned a phonetic complexity level (ranging from 1–5) as described above. Values for each sentence were summed, yielding an utterance-level complexity score.

Longer sentences naturally yield higher phonetic complexity scores due to the increased number of words and, thus, phonemes as sentence length increases. To reduce the confounding effect of sentence length on phonetic complexity, we calculated average complexity scores per word by dividing the total phonetic complexity of each sentence by the number of words in the sentence. We then examined the impact of average word-level phonetic complexity on intelligibility by separating sentences into phonetic complexity quartile groupings. The first quartile group contained sentences that had average per word complexity scores in the bottom 25% of the distribution of all sentences in the corpus. The second quartile group contained sentences that

Table II. Phonetic complexity characteristics of TOCS sentences.

	Total number of words across 10 sentences	Average phonetic complexity within sentence length	Phonetic complexity range within sentence length	Phonetic complexity SD within sentence length	Average phonetic complexity per word	Phonetic complexity range per word	Phonetic complexity SD per word
2-word sentences	20	10.58	7–19	2.64	5.16	2.25–8.00	1.24
3-word sentences	30	15.50	11–21	2.81	5.03	3.00–7.00	.98
4-word sentences	40	19.35	9–25	5.42	4.93	2.25–8.00	1.30
5-word sentences	50	26.22	20–35	4.80	5.14	2.25–7.00	1.01
6-word sentences	60	27.68	16–46	6.30	4.81	2.25–8.00	1.19
7-word sentences	70	33.55	24–43	5.71	4.87	2.25–8.00	.92

SD, standard deviation.

had average per word complexity scores between 26–50% of the distribution of all sentences in the corpus. The third quartile group contained sentences with average per word complexity scores between 51–75% of the distribution of all sentences in the corpus. Finally, the fourth quartile group contained sentences with average per word complexity scores between 76–100% of the distribution. Phonetic complexity characteristics of the TOCS sentences that were employed in this study are provided in Table II. Quartile groups were used as an independent variable to examine differences in intelligibility based on phonetic complexity.

Experimental design and statistical procedures

Two different experimental designs and three different analyses were employed for this study. The first question focused on characterizing differences across stimulus lengths within each of the groups of children. A 3 × 6 repeated measures design was used to address this question. The within-subjects variable was stimulus length, and its levels were utterances of six different lengths, 2–7 words). The between-subjects variable was group, with children separated into the following groups: CP with speech motor impairment (SMI), CP without speech motor impairment (NSMI), and typically-developing (TD). Analyses were conducted using ANOVA procedures within groups, with an alpha of .01 allotted to each of the three within-group omnibus tests. Follow-up pairwise comparisons ($n = 15$) were allotted a total alpha level of .05. A Bonferroni correction was applied by dividing the alpha evenly among tests to maintain an overall alpha level of .05. To be considered significant, an alpha less than or equal to .003 was necessary.

The second question focused on the impact of phonetic complexity on intelligibility within each of the groups of children. To address this question, a 3 × 4 repeated measures design was used. The within-subjects variable was phonetic complexity quartiles (four levels). The between-subjects variable was group, with children separated into the following groups: CP with speech motor impairment (SMI), CP without speech motor impairment (NSMI), and typically-developing (TD). Analyses were conducted using ANOVA procedures within groups, with an alpha of .01 allotted to each of the three within-group omnibus tests. Follow-up pairwise comparisons ($n = 6$) for each group were allotted an alpha level of .05, which was again divided evenly among tests in accordance with Bonferroni correction procedures. To be considered significant, an alpha less than or equal to .008 was necessary.

The third question examined the relative contributions of phonetic complexity and sentence length to predicting intelligibility for children with dysarthria. We also examined individual differences among children within the SMI group with regard to predictors of intelligibility. Analyses were completed using regression procedures within the SMI group as a whole and within each individual child. As both sentence length and average phonetic complexity of words were hypothesized to impact intelligibility, both predictors were simultaneously entered into group and child regression models.

Results

Effect of sentence length on intelligibility

Descriptive data showing the effect of utterance length on intelligibility for each of the three dif-

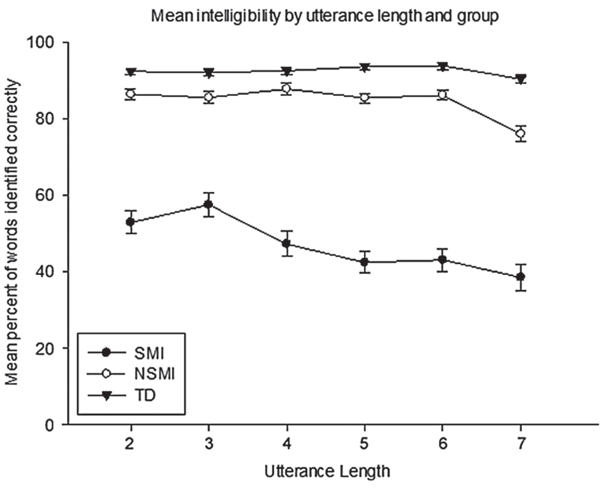

Figure 1. Mean intelligibility by utterance length and group.

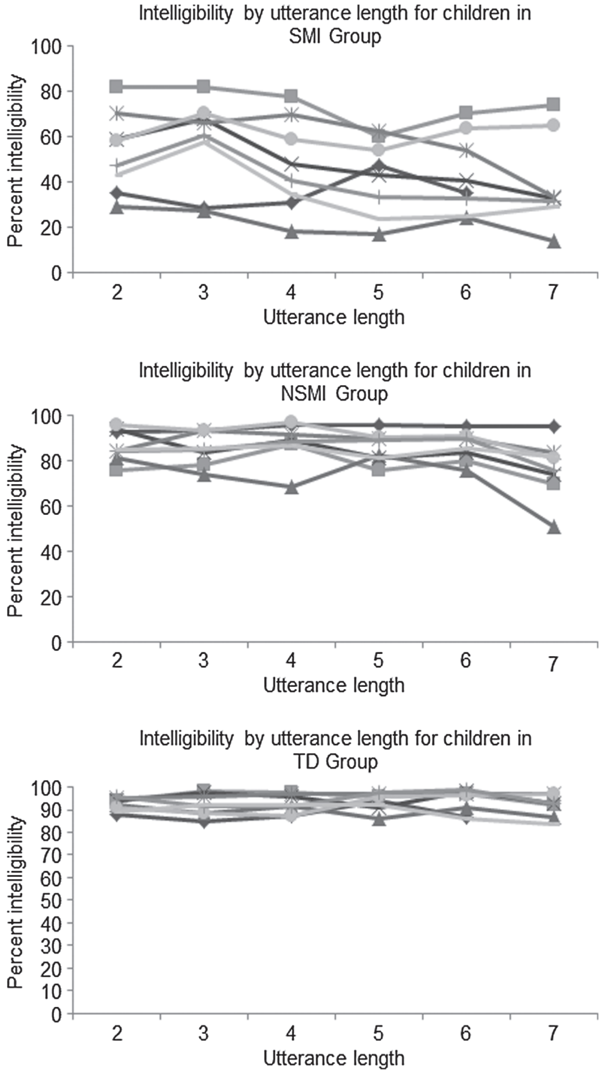

Figure 2. Intelligibility by utterance length.

ferent groups are shown in Figure 1. Descriptive results suggest that intelligibility decreased as utterance length increased for both groups of children with CP, but that utterance length had little impact on intelligibility for children in the TD group. Data for individual children within each group are shown in Figure 2. Results suggest considerable variability among children in the SMI group, less variability among children in the NSMI group, and little variability among children in the TD group.

ANOVA omnibus results revealed that the main effect of utterance length was significant within each group of children (NSMI: $F_{5,190} = 14.95$; $p < .001$; SMI: $F_{5,170} = 25.55$; $p < .001$; TD: $F_{5,170} = 3.91$, $p < .001$). Follow-up contrasts are presented in Table III. Results indicated that, for children in the TD group, the only significant difference was between intelligibility of 6- vs 7-word utterances. For children in the NSMI group, 7-word utterances were significantly less intelligible than all other utterances, but no other contrasts were significant. For children in the SMI group, 2-and 3-word utterances were significantly more intelligible than 4-, 5-, 6-, and 7-word utterances, but no other differences were significant.

Effect of phonetic complexity on intelligibility

Descriptive data showing the effect of phonetic complexity on intelligibility for each of the three different groups are shown in Figure 3. Descriptive results suggest some fluctuation in intelligibility that appears to be quadratic in nature for children in the NSMI and TD groups, and a decreasing trend in intelligibility as phonetic complexity increased for children in the SMI groups. Data for individual children within each group are shown in Figure 4. Results suggest considerable variability among children in the SMI group, less variability among children in the NSMI group, and little variability among children in the TD group.

ANOVA omnibus results revealed that the main effect of phonetic complexity was significant within each group of children (NSMI: $F_{3,114} = 11.55$; $p < .001$; SMI: $F_{3,117} = 15.70$; $p < .001$; TD: $F_{3,117} = 7.25$, $p < .001$). Follow-up contrasts are presented in Table III. Results indicated that, for children in the TD group, significant differences were found between complexity quartiles 1 vs 3 and 3 vs 4. For children in the NSMI group, significant differences were found between complexity quartiles 1 vs 3, and 3 vs 4. For children in the SMI group, intelligibility was higher for complexity quartile 1 than for any other quartile; there were no other significant quartile differences.

Contribution of sentence length and complexity to predicting intelligibility

In order to determine the relative contributions of sentence length and phonetic complexity to intelligibility for children with dysarthria, both sentence characteristics were entered into a multiple regression model for this group. Results indicated both average phonetic complexity of words ($B = -3.99$, $p = .002$) and sentence length ($B = -3.37$, $p < .001$) were significant predictors of intelligibility for children with SMI. Thus, sentences with more phonetically complex words were less intelligible to listeners, controlling for sentence length. Likewise, longer sentences were also related to decreased intelligibility, controlling for phonetic complexity. The whole model explained a significant, but small amount of variability in intelligibility within the SMI group ($R^2 = .05$, $p < .001$).

Visual examination of the data (Figures 2 and 4) showed considerable variation in the relationship between sentence characteristics and intelligibility among individual children in the SMI group. For each of the eight children with dysarthria, an individual regression analysis was conducted to examine the effect of sentence characteristics (length in words and average phonetic complexity

Table III. Pairwise t-tests examining within-group differences across complexity categories and utterance lengths.

Contrast	Mean difference	Standard deviation	T	p-value
TD				
Phonetic complexity quartiles				
Quartile 1 vs Quartile 2	1.63	5.96	1.73	.091
Quartile 1 vs Quartile 3	3.96	4.77	5.25	.000**
Quartile 1 vs Quartile 4	.73	4.24	1.08	.283
Quartile 2 vs Quartile 3	2.33	7.52	1.96	.057
Quartile 2 vs Quartile 4	−.90	5.92	−.96	.339
Quartile 3 vs Quartile 4	−3.24	5.36	−3.82	.000**
Utterance length				
2-word vs 3-word	.28	6.85	.26	.791
2-word vs 4-word	−.12	5.45	−.14	.886
2-word vs 5-word	−1.24	6.92	−1.13	.266
2-word vs 6-word	−1.42	5.76	−1.55	.128
2-word vs 7-word	2.63	6.51	2.39	.022
3-word vs 4-word	−.41	4.97	−.53	.602
3-word vs 5-word	−1.52	6.55	−1.47	.149
3-word vs 6-word	−1.71	5.58	−1.93	.061
3-word vs 7-word	2.78	6.82	2.41	.021
4-word vs 5-word	−1.11	6.91	−1.02	.316
4-word vs 6-word	−1.29	6.10	−1.34	.188
4-word vs 7-word	2.92	5.93	2.91	.006
5-word vs 6-word	−.18	6.24	−.18	.856
5-word vs 7-word	3.22	7.02	2.71	.010
6-word vs 7-word	4.47	5.33	4.96	.000*
NSMI				
Phonetic complexity quartiles				
Quartile 1 vs Quartile 2	1.16	7.73	.94	.353
Quartile 1 vs Quartile 3	6.56	7.74	5.29	.000**
Quartile 1 vs Quartile 4	.44	6.27	.44	.662
Quartile 2 vs Quartile 3	5.39	9.15	3.68	.001**
Quartile 2 vs Quartile 4	−.72	7.46	−.60	.550
Quartile 3 vs Quartile 4	(6.12	8.84	−4.32	.000**
Utterance length				
2-word vs 3-word	.88	11.02	.50	.618
2-word vs 4-word	−1.35	10.93	−.77	.444
2-word vs 5-word	1.00	10.39	.60	.550
2-word vs 6-word	.31	9.77	.20	.842
2-word vs 7-word	10.42	12.48	5.22	.000*
3-word vs 4-word	−2.24	9.33	−1.49	.142
3-word vs 5-word	.11	10.03	.07	.943
3-word vs 6-word	−.57	7.72	−.46	.645
3-word vs 7-word	9.54	10.07	5.91	.000*
4-word vs 5-word	2.35	8.91	1.59	.120
4-word vs 6-word	1.67	7.17	1.45	.155
4-word vs 7-word	11.78	8.91	8.25	.000*
5-word vs 6-word	−.69	6.23	−.69	.494
5-word vs 7-word	9.42	11.85	4.96	.000*
6-word vs 7-word	10.11	9.04	6.98	.000*
SMI				
Phonetic complexity quartiles				
Quartile 1 vs Quartile 2	8.37	11.69	4.53	.000**
Quartile 1 vs Quartile 3	12.95	12.16	6.73	.000**
Quartile 1 vs Quartile 4	12.29	11.90	6.53	.000**
Quartile 2 vs Quartile 3	4.57	15.80	1.83	.074
Quartile 2 vs Quartile 4	3.91	17.01	1.45	.153
Quartile 3 vs Quartile 4	−.66	10.91	−.38	.704
Utterance length				
2-word vs 3-word	−4.63	11.56	−2.53	.016
2-word vs 4-word	5.63	10.95	3.25	.002*
2-word vs 5-word	10.43	15.46	4.27	.000*
2-word vs 6-word	9.78	15.14	4.09	.000*
2-word vs 7-word	15.67	17.58	5.27	.000*
3-word vs 4-word	10.25	13.58	4.77	.000*
3-word vs 5-word	15.06	19.15	4.97	.000*
3-word vs 6-word	14.41	18.11	5.03	.000*
3-word vs 7-word	21.86	15.77	8.20	.000*
4-word vs 5-word	4.80	12.01	2.58	.016
4-word vs 6-word	4.15	13.32	1.97	.056
4-word vs 7-word	9.79	15.69	3.69	.001*
5-word vs 6-word	−.64	11.69	−.35	.728
5-word vs 7-word	2.01	16.04	.75	.462
6-word vs 7-word	4.44	11.71	2.24	.031

SMI, speech motor impairment; NSMI, no speech motor impairment; TD, typically-developing.
Criterion p-values for significance: **p ≤ .008; *p ≤ .003.

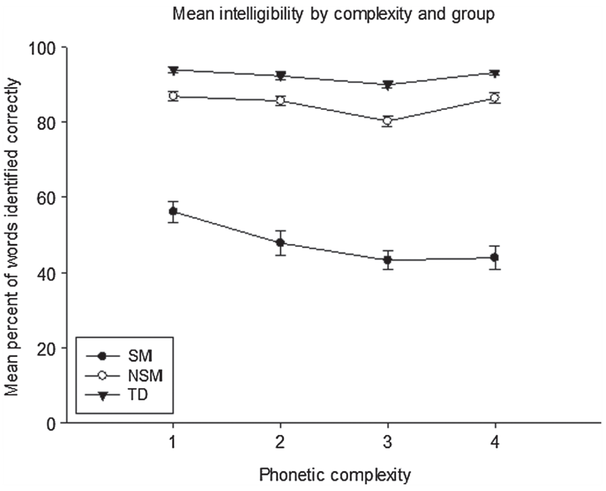

Figure 3. Mean intelligibility by complexity and group.

of words) on intelligibility for individual children. Results showed considerable variation in the predictive nature of sentence characteristics across children (see Table IV). R^2 values ranged from .02–.24, indicating the sentence characteristics explained very little of the variation in intelligibility for some children, but a significant amount of the variability for others. For three of the children with dysarthria (Children #4, 5, and 8), sentence length (in words) was a significant predictor of intelligibility, controlling for phonetic complexity. Phonetic complexity was not a significant predictor of intelligibility for any of these three children. However, child #1 showed the opposite pattern, with average phonetic complexity emerging as a significant predictor of intelligibility, controlling for sentence length, but no independent effect of sentence length. For child #7, both phonetic complexity and sentence length were significantly related to intelligibility. For the remaining three children with dysarthria, neither sentence length nor phonetic complexity was a significant predictor of intelligibility.

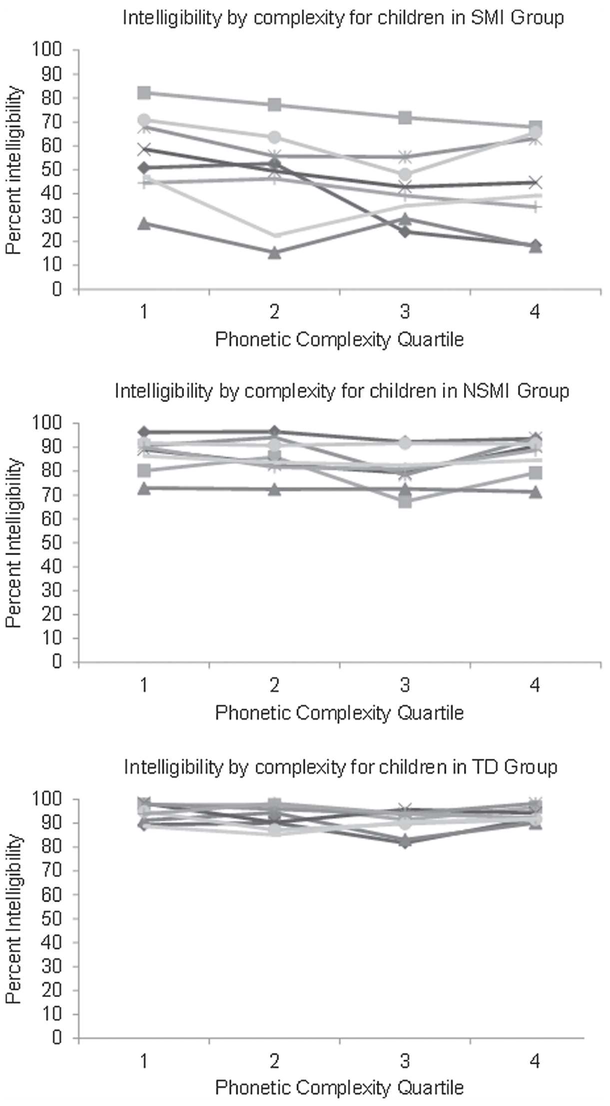

Figure 4. Intelligibility by complexity.

Discussion

There were several key findings from this study. First, both sentence length and phonetic complexity had an effect on intelligibility, but this effect differed between groups of children (those with and without SMI). In addition, different relationships were found between sentence characteristics and intelligibility for individual children with SMI, independent of severity. Each of these findings is discussed in detail below.

Effect of sentence length on intelligibility

Results of this study showed that intelligibility of 5-year-old children was affected by sentence length. However, the magnitude of this finding was directly affected by the presence of speech motor impairment. Children without dysarthria (NSMI and TD groups) showed a modest reduction in intelligibility with sentences of the longest length (7-words). The overall pattern of intelligibility across sentences of 2–6-words in length was generally stable across sentences, with ~92% of words identified correctly for TD children, and 86% of words identified correctly for NSMI children. However, for both groups there was a significant decline in intelligibility for 7-word utterances (see Figure 1). This effect was more pronounced for children in the NSMI group, with the magnitude ranging between 10–12%. This result is slightly different from findings of Hustad et al. (2012), who demonstrated that intelligibility of children with CP and NSMI increased with sentence length up to 4-word utterances, before declining in longer utterances. In the earlier study, the authors noted that the observed peak in intelligibility coincided with expected mean length of utterance in words (MLU-W) for children at ~4–5 years of age, and proposed a possible relationship between language

Table IV. Within-child multiple regression models examining the influence of phonetic complexity and sentence length on intelligibility. Overall sentence intelligibility across all stimulus sentences also presented for each child.

	B				
Child	Constant	Phonetic complexity	Sentence length	Multiple R^2	Sentence intelligibility
1	97.05 (21.85)	−12.92 (3.50)***	.73 (2.70)	.24	34.9%
2	109.76 (17.45)	−4.22 (2.77)	−3.17 (1.83)	.08	73.5%
3	44.16 (14.83)	−2.14 (2.34)	−2.62 (1.75)	.06	21.0%
4	101.98 (20.98)	−4.56 (3.32)	−6.84 (2.18)**	.16	46.8%
5	102.58 (15.72)	−3.00 (2.49)	−6.30 (1.77)***	.21	60.5%
6	76.57 (19.34)	−2.93 (3.04)	−.10 (2.02)	.02	61.1%
7	97.96 (19.60)	−6.34 (3.09)*	−5.65 (2.02)**	.15	40.2%
8	55.92 (21.53)	.50 (3.38)	−5.12 (2.25)*	.09	34.0%

Observed p-values: $^{*}p \le .05$; $^{**}p \le .01$; $^{***}p < .001$.

development and development of intelligibility in this age group. This same peak in intelligibility at the expected MLU-W was not noted in the present study for 5-year old children. However, results did confirm that sentences of the longest lengths were less intelligible than shorter sentences, consistent with the results of Hustad et al. (2012). Collectively, the results support the hypothesis that, when children produce sentences beyond their habitual speaking length, the increased demands on speech motor performance, and/or their developing phonological systems may result in reduced speech intelligibility, even for children without SMI. Another potential conclusion is that the increased language processing demands of producing longer sentences require children to devote more attention to language formulation and detract from their speech motor performance.

It is also worth noting that intelligibility scores for typically-developing 5-year old children in the present study ranged from ~ 91–94% for 2–7-word utterances. Hustad et al. (2012) reported intelligibility scores ranging from 85–92% for typically-developing 4-year old children for 2–7-word utterances. Across the two studies, results suggest that intelligibility appears to become more stable and less variable across utterances of different lengths as children develop. Further, the absolute increase in sentence intelligibility between 4–5 years of age was up to 9%, depending on the length of utterance for the 4-year old children. These data demonstrate that substantial advances in intelligibility development continue into the 5th year for typically-developing children, and children at this age have not yet reached a ceiling of 100% for intelligibility.

For children in the SMI group (all of whom had dysarthria), intelligibility was reduced markedly overall relative to children without SMI. The pattern of results indicated that intelligibility was highest for utterances that were 2–3 words in length, and considerably lower for longer utterances, regardless of length. The magnitude of this difference ranged from 6–17%. In 4-year-old children with CP and speech motor impairment, Hustad et al. (2012) reported a gradual decreasing pattern in intelligibility with increased sentence length, but this finding was generally not as robust as in the present study. There are several possible explanations for this finding. The most obvious is that children with CP and SMI are extremely heterogeneous and it is difficult to make absolute comparisons across studies involving different children. In Hustad et al. (2012), 4-year-old children with speech motor impairment were sub-divided into groups based on the presence or absence of co-occuring language impairment. While language scores were not a selection criteria for the present study, children in the SMI group were generally higher functioning, as only those children able to repeat longer utterances were included. In fact, all but two children in the SMI group had language comprehension scores in the average range for their age. Compared to 4-year-old children with speech motor impairment and normal language skills in Hustad et al. (2012), peak intelligibility of the 5-year-old SMI group in the present study was ~20% higher in the present study. This discrepancy may be related to individual differences among subjects in the two studies with regard to severity of speech motor involvement; however, it also may be related to advancing phonological development. A possible interpretation is that, due to gains in phonological development, 5-year-old SMI children in the present study were more intelligible than 4-year-olds for shorter sentence lengths, but at longer sentence lengths, increased speech motor demands counteracted the benefit of their more advanced phonological systems.

Effect of phonetic complexity on intelligibility

The results of this study showed that intelligibility of 5-year-old children was also affected by phonetic complexity. As with sentence length, the magnitude of the effect of phonetic complexity on intelligibility was directly affected by the presence of speech motor impairment. For children without dysarthria (TD and NSMI groups), the effect was generally quite small. Sentences in the lowest phonetic complexity quartile were significantly more intelligible than sentences in the 3rd complexity quartile, as expected. However, intelligibility of the most phonetically complex sentences (those in the 4th quartile) was higher than sentences in the 3rd complexity quartile for these groups of children. This is an unusual result, as we expected sentences with more phonetically complex words would be more difficult for children to produce, and thus be less intelligible to listeners. However, this finding highlights the fact that linguistic factors are also likely to impact the intelligibility of sentences. When orthographically transcribing sentences, listeners in this study were making lexical judgements about words the child produced, rather than phonetic judgements regarding speech sound accuracy. Despite the phonetic make-up of words in the sentences, some sentences may have been more linguistically predictable than others. As all children in the study produced the same set of sentences, it is possible that sentences falling in the 4th phonetic complexity quartile were more linguistically predictable than those in the 3rd quartile, thus making them more intelligible to listeners. In addition, phonetic complexity quartiles were not balanced for sentence length. Therefore, it is possible that the relative proportions of different sentence lengths within complexity quartiles may have influenced results; however, examination of the distribution of sentence lengths across phonetic complexity quartiles showed similar relative proportions of sentence lengths between utterances in the 3rd and 4th complexity quartiles. It is also important to note that, while statistically significant, absolute differences in intelligibility between complexity quartiles for the TD and NSMI groups were small, and likely made little practical difference to intelligibility.

For children in the SMI group, there was a significant disadvantage to intelligibility for utterances with average complexity scores above the first quartile. The magnitude of this effect ranged from 7–9% for sentences with the lowest average word complexity compared to those in higher complexity levels. These results support the hypothesis that increased phonetic complexity has a differential negative impact on intelligibility for children with dysarthria compared to those without speech motor impairment. In addition, the contrast in patterns across groups suggest that the coinciding influences of linguistic context and speech motor demands may have different effects on children with and without dysarthria. If, as suggested above, sentences with the highest average phonetic complexity were more linguistically predictable for listeners, the absence of this effect on intelligibility for children in the SMI group suggests that benefits of linguistic context may be mitigated by increased demands on speech motor control for children with dysarthria. In other words, the cost of increased speech motor complexity may override the benefit of greater linguistic predictability to intelligibility for children with dysarthria.

Individual differences in predictive nature of sentence characteristics

In addition to group differences in the effect of sentence length and phonetic complexity on intelligibility, there was wide variability in the relative contribution of sentence characteristics to intelligibility across individual children with dysarthria. Results of within-child multiple regression models showed that the effect of sentence characteristics on intelligibility varied considerably across individual children with dysarthria; however, reasons for these individual variations were not as clear.

Based on results of group analyses, one might expect children with more severe dysarthria to show a greater decline in intelligibility with increased sentence length and phonetic complexity than children with mild speech impairment. However, our data showed no clear pattern between the predictive abilities of sentence characteristics and severity of dysarthria, as overall intelligibility scores varied widely across children who showed similar relationships between factors. In fact, the two children who showed no significant relationship between sentence characteristics and intelligibility were the children with the highest and lowest overall intelligibility scores. These results illustrate the complex nature of relationships between speech motor control and intelligibility; while intelligibility measures represent an overall index of functional dysarthria severity, children with very different patterns of impairment in speech motor control may have similar levels of intelligibility.

The variation in the individual relationships between sentence characteristics and intelligibility seen among the eight children with dysarthria in this study suggest that children's individual speech motor patterns may interact with sentence features in different ways to influence intelligibility. For example, child 3, who had the lowest overall intelligibility of the group, had severe and pervasive hypernasality. For this child, hypernasality may affect her intelligibility similarly across sentences of all lengths and phonetic complexities, thus mitigating the effect of sentences characteristics on intelligibility. Furthermore, the way in which increased sentence length taxes a child's speech motor system is quite different from the motor demands of greater phonetic complexity. Longer sentences impose higher demands on breath support for speech and require greater endurance for production, possibly inducing fatigue for children with dysarthria. In contrast, increased phonetic complexity imposes greater demands on fine control of speech articulator movements. Thus, individual patterns in the influence of sentence characteristics on intelligibility may provide information about the way particular children's speech motor systems are most taxed. Some children's intelligibility may be more affected by increased demands on endurance, while others may be more affected by demands on fine control of tongue movements. Examining individual relationships in detail is beyond the scope of this study, but our results suggest the importance of taking individual speech motor profiles of children with dysarthria into consideration when assessing the relationship of sentence characteristics to intelligibility.

Clinical implications

Results of the present study have important clinical implications when considering treatment methods for maximizing intelligibility of children with dysarthria. While the effect of sentence length on intelligibility has been a focus of many research studies, phonetic complexity of utterances has received less attention. Our data suggest that reducing both the length and phonetic complexity of utterances may aid in enhancing intelligibility for children with dysarthria. However, it is clear that these sentence characteristics have different influences on intelligibility for different children with dysarthria. This highlights the importance of considering each child's individual speech motor profile when deciding on treatment strategies. Future investigations examining children's speech motor patterns in conjunction with the contribution of sentence characteristics to their intelligibility are important to further our understanding of these relationships. Understanding relationships between individual speech motor profiles and factors influencing intelligibility could lead to development of improved treatment strategies for sub-groups of children with dysarthria.

Limitations and future directions

The present study was based on data from children within a narrow age range, which reduced the heterogeneity of our sample, but limits the generalizability of our findings across age groups. Although comparable to other studies of children with CP, the number of children in the current sample was small. Thus, our findings should be considered preliminary, and would be strengthened by additional studies examining the effects of sentence length and phonetic complexity across age groups and with a larger sample of children. In addition, phonetic complexity of words in stimulus sentences was quasi-controlled in the present study. As a result, the sentences in different complexity quartiles were not fully balanced for length or other linguistic variables, including predictability of utterances. Future studies balancing phonetic complexity with linguistic sentence characteristics may provide further insight into the relative contributions of these sentence characteristics to intelligibility. Results of the current study also indicated that intelligibility of 5-year-old children without speech motor impairment declined at the longest sentence lengths, possibly indicating a reduction in intelligibility when children repeat sentences longer than their assumed habitual utterance length. Future investigations directly comparing children's measured MLU to their intelligibility at different utterance lengths could provide valuable information regarding the interaction between language development and intelligibility in children with and without dysarthria.

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