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Research Article

# Effects of Rate Manipulation on Intelligibility in Children With Cerebral Palsy

Ashley Sakash,[a] Tristan J. Mahr,[a] Phoebe E. M. Natzke,[a] and Katherine C. Hustad[a,b]

**Purpose:** We evaluated the effects of a speech supplementation strategy to reduce rate and improve intelligibility in children with cerebral palsy.
**Method:** Twenty-five children with cerebral palsy ($M_{age}$ = 12.08 years) completed a structured speaking task in 2 speech conditions: habitual speech and slow speech. Fifteen children had mild intelligibility deficits; 10 had moderate–severe intelligibility deficits. In each condition, children repeated utterances of 2–7 words in length. In the habitual speech condition, children used their natural and unaltered speaking rate. In the slow speech condition, children were cued to insert pauses between words. Intelligibility ratings were obtained from orthographic transcriptions by unfamiliar adult listeners ($n$ = 100). Speech rate, in words per minute, was measured for each utterance.
**Results:** All children, regardless of severity group, were able to reduce their rate of speech when implementing the slow speech strategy. Only children in the moderate–severe group showed an improvement in intelligibility when implementing the slow speech strategy. Although there was considerable individual variability, there was a greater improvement in intelligibility for longer utterances compared to shorter ones.
**Conclusion:** A slow speech strategy may be beneficial for children with moderate–severe intelligibility deficits who speak in longer utterances. Future studies should seek to further examine the clinical feasibility of slow speech for children with reduced intelligibility.

Approximately half of all children with cerebral palsy (CP) have dysarthria, a neurologically based speech disorder caused by impaired speech motor control (Nordberg, Miniscalco, Lohmander, & Himmelmann, 2013). Dysarthria can affect one or several speech subsystems and is characterized by features such as imprecise articulation, short breath groups or irregular breathing, harsh or breathy vocal quality, reduced prosody, and impaired speech rate (Darley, Aronson, & Brown, 1969). The combination of these features often leads to reduced speech intelligibility, putting children at risk for social isolation and a diminished quality of life as they struggle to communicate their thoughts and experiences through the use of speech (Colver et al., 2015; Dang et al., 2015; Dickinson et al., 2007; Fauconnier et al., 2009). Recent work has also found speech differences and reductions in speech intelligibility even for children with CP who do not have a clinical diagnosis of dysarthria relative to a typically developing comparison group (Hustad, Sakash, Broman, & Rathouz, 2019; Hustad, Schueler, Schultz, & DuHadway, 2012). Thus, improving speech intelligibility for any child who is not meeting age-level expectations for intelligibility is a primary goal of therapy (Ansel & Kent, 1992).

A limited number of studies have examined the outcomes of treatment approaches for children with dysarthria (see Pennington, Parker, Kelly, & Miller, 2016, for a systematic review). Pennington and colleagues used a multiple subsystems approach to teach 5- to 18-year-old children with dysarthria secondary to CP strategies to control breath support and phonation and to reduce speech rate in an intensive 6-week intervention program (Pennington, Miller, Robson, & Steen, 2010; Pennington, Roelant, et al., 2013). Although there was considerable variability in children's performance, the treatment approach overall was associated with gains in intelligibility in single-word and connected speech to both familiar and unfamiliar listeners, and these gains were maintained 6 and 12 weeks postintervention. Results from this study suggest that therapy aimed at controlling respiratory support, phonation, and speech rate

[a]Waisman Center, University of Wisconsin–Madison
[b]Department of Communication Sciences and Disorders, University of Wisconsin–Madison

Correspondence to Ashley Sakash: asakash@wisc.edu

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leads to improved intelligibility for children with CP and dysarthria. However, because multiple strategies were taught at the same time, it is impossible to determine what effect each individual strategy had on speech intelligibility.

In a separate group of treatment studies, Boliek and Fox (Boliek & Fox, 2014, 2017; Fox & Boliek, 2012) investigated the effects of the well-known Lee Silverman Voice Treatment–LOUD (LSVT LOUD; Ramig, Pawlas, & Countryman, 1995) approach on speech production in children with CP between 5 and 10 years of age. Using the LSVT LOUD approach, results showed percentage point increases in single-word intelligibility, ranging from 7 to 16, as judged by expert listeners immediately following treatment. However, at 12 weeks posttreatment, follow-up intelligibility results were variable (Boliek & Fox, 2014, 2017). These studies suggest that the LSVT LOUD approach, when taught in an intensive treatment program, may be a promising treatment strategy for improving single-word intelligibility in children with dysarthria secondary to CP. The effect of this strategy on multiword intelligibility, though, is unknown.

Levy, Chang, Ancelle, and McAuliffe (2017) also investigated the effects of loud speech (cued as “speak with your strong voice”) and clear speech (cued as “speak with your big mouth”) on intelligibility for eight children with dysarthria secondary to CP. In particular, they examined the immediate effects of teaching children to manipulate aspects of their speech through modeling and prompting. Results revealed that 4- to 14-year-old children with dysarthria and CP were able to manipulate their speech clarity and vocal intensity with simple instruction and verbal and visual cueing. In addition, clear speech cues resulted in greater word and sentence durations for the children. Both cues resulted in overall gains in single-word and multiword intelligibility as judged by unfamiliar listeners, with the “clear speech” cue resulting in greater gains than the “loud speech” cue. However, there was individual variability in intelligibility changes for both conditions. In the “clear speech” condition, percentage point changes in single-word intelligibility ranged from no change to an approximate gain of 40. In the “loud speech” condition, percentage point changes in single-word intelligibility ranged from approximately −10 (a decrease in intelligibility) to an approximate gain of 23. Overall, this study suggests children with CP and dysarthria can manipulate their speech to improve intelligibility, but these improvements vary greatly over children.

Another approach that has shown promise for increasing intelligibility in adults with CP is the use of rate reduction. Studies have shown that adults with dysarthria secondary to CP and other etiologies are able to reduce their rate of speech following simple teaching and cueing (Hustad & Sassano, 2002; McAuliffe, Fletcher, Kerr, O’Beirne, & Anderson, 2017; McHenry, 2003; Pilon, McIntosh, & Thaut, 1998; Yorkston, Hammen, Beukelman, & Traynor, 1990). In these studies, rate reduction was accomplished through the use of external pacing and/or deliberate insertion of interword pauses with the goal of reducing coarticulation, creating clearer word boundaries, and providing listeners with interword processing time. Regardless of dysarthria etiology, these studies have shown that reducing rate of speech leads to increases in intelligibility ratings by unfamiliar listeners (Hustad & Sassano, 2002; McAuliffe et al., 2017; McHenry, 2003; Pilon et al., 1998; Yorkston et al., 1990).

In the current study, we asked whether children with CP would be able to manipulate their speech rate in a highly structured task and whether changes in speech rate would lead to increased intelligibility. Separate studies that focus on the effects of rate reduction in children are crucial because there are a number of variables associated with ongoing development that limit the extent to which findings from adults generalize to children. In particular, language and speech are still developing in children, and therefore, children may show developmental constraints in their expressive/receptive language and speech production and their cognitive and metacognitive abilities that may influence the effectiveness of different strategies. For example, a strategy used with adults that requires a high level of metacognitive awareness may require adjustments for children who are still developing those skills. Thus, studies that document the effects of speech manipulation strategies, such as rate reduction, under highly controlled experimental conditions are necessary in order to determine whether actual intervention studies are warranted. To our knowledge, this is the first study to examine the independent contribution of speech rate manipulation to intelligibility in children with CP.

We used elements of a speech supplementation intervention examined previously in adults (Crow & Enderby, 1989; Hustad, Jones, & Dailey, 2003) as a framework for structuring and teaching a rate reduction strategy to children. Specifically, we examined whether children with CP at risk for reduced speech intelligibility could slow their rate of speech using a structured speech supplementation paradigm, hereafter referred to as *slow speech,* and, subsequently, whether reducing rate of speech would lead to increases in speech intelligibility. Furthermore, we examined the impact of utterance length on intelligibility in both habitual and slow speech conditions to determine whether rate reduction had a differential impact on shorter or longer utterances. In a heterogeneous population such as those with CP, researchers often group individuals based on common features (e.g., dysarthria type, type of CP) in order to obtain a clearer view of the effects of treatment or association between variables (Tjaden & Wilding, 2004). In the current study, we separated children into mild and moderate–severe groups and examined the differential effect of severity on the use of slow speech. We asked the following research questions in this study:

1. Is there a difference in speech rate for utterances produced with habitual speech versus utterances produced with a slow speech strategy for children with

mildly reduced intelligibility and for children with moderately–severely reduced intelligibility?

   a. What is the effect of utterance length on speech rate for habitual speech and for slow speech for children in each group?

2. Is there a difference in speech intelligibility for utterances produced with habitual speech versus utterances produced with a slow speech strategy for children with mildly reduced intelligibility and for children with moderately–severely reduced intelligibility?

   a. What is the effect of utterance length on speech intelligibility for habitual speech and for slow speech for children in each group?

Based on previous research with adults (Hustad & Sassano, 2002; McAuliffe et al., 2017; McHenry, 2003; Pilon et al., 1998; Yorkston et al., 1990), we hypothesized that use of the slow speech strategy would lead to a reduction in speech rate for all children but that there would be individual variation among children due to varying levels of severity. In a previous work by Pilon et al. (1998), adult speakers who had moderate–severe dysarthria benefited more than speakers with mild dysarthria from rate reduction cues. We hypothesized that severity would influence the outcome of the slow speech strategy for both speech rate and speech intelligibility such that children with lower habitual speech intelligibility would benefit most from the strategy. Furthermore, we hypothesized that the slow speech strategy would be more effective for longer utterances than for shorter ones, owing to findings from previous studies showing that longer utterances were generally less intelligible than shorter ones (Allison & Hustad, 2014; Hustad et al., 2012) and that longer utterances were produced at a faster rate than shorter ones (Darling-White, Sakash, & Hustad, 2018).

# Method

## *Participants*

### Children With CP

Participants were drawn from a larger ongoing longitudinal study on communication development in children with CP. Inclusion criteria for the larger study required that children (a) have a medical diagnosis of CP and (b) have hearing abilities within normal limits as documented by either formal audiological evaluation or distortion product otoacoustic emission screening. The children who participated in this cross-sectional project met the following additional criteria: (c) use speech as their primary method of communication, (d) be able to produce elicited sentences at least three words in length following an adult model, and (e) have no clinical diagnosis of autism spectrum disorder.

Twenty-eight children with CP met these criteria. For three children, the rate reduction strategy could not be administered due to child behavior noncompliance and/or child fatigue. The final sample for the current study consisted of 25 children (10 boys; $M_{age}$ = 12;1 [years;months], age range: 9;8–15;10). Table 1 reports demographic information. All children were born between 2001 and 2007.

In order to look at the contribution of severity to the outcome of the slow speech strategy, we separated children into two groups according to their habitual intelligibility scores. Habitual intelligibility scores were an important dependent measure in this study, which we used to characterize change associated with the implementation of slow speech. However, we also used habitual intelligibility scores as an empirical way to separate children into severity groups. Though we recognize that using a dependent variable as a grouping variable is not ideal, it was the most ecologically valid approach to creating severity groupings, which still allowed us to examine change in intelligibility

**Table 1.** Demographic characteristics of participants.

| Characteristic | Mild *n* = 15 | Moderate–severe *n* = 10 |
|---|---|---|
| Male–female ratio | 8:7 | 2:8 |
| Age in months, *M* (*SD*) | 150 (25) | 140 (18) |
| Language SS, *M* (*SD*) | 92 (21) | 69 (21) |
| Leiter Brief IQ,[a] *M* (*SD*, *n*) | 79 (15, 11) | 61 (18, 6) |
| BRIEF GEC *T* score, *M* (*SD*, *n*) | 66 (12, 12) | 61 (13, 9) |
| Habitual intelligibility, *M* (*SD*) | 95.1 (4.4) | 50.1 (26.0) |
| Cerebral palsy type | | |
| Spastic | | |
| Diplegia | 3 | 2 |
| Hemiplegia (left) | 4 | 2 |
| Hemiplegia (right) | 6 | 0 |
| Triplegia | 0 | 1 |
| Quadriplegia | 1 | 1 |
| Dyskinetic | 0 | 0 |
| Ataxic | 0 | 2 |
| Mixed | 0 | 1 |
| Hypotonic | 1 | 0 |
| Unknown | 0 | 1 |
| Gross Motor Classification System[b] | | |
| I | 9 | 1 |
| II | 3 | 6 |
| III | 3 | 0 |
| IV | 0 | 3 |
| V | 0 | 0 |
| Manual Abilities Classification System[c] | | |
| I | 4 | 2 |
| II | 8 | 4 |
| III | 2 | 3 |
| IV | 1 | 1 |
| V | 0 | 0 |
| Viking Speech Scale[d] | | |
| I | 10 | 1 |
| II | 5 | 6 |
| III | 0 | 3 |
| Dysarthria | 11 | 10 |
| ADHD | 7 | 1 |
| Seizures | 1 | 4 |

*Note.* SS = standard score; BRIEF = Behavior Rating Inventory of Executive Function (Gioia et al., 2000, 2015); GEC = Global Executive Composite; ADHD = attention-deficit/hyperactivity disorder.

[a]Roid & Miller (1997). [b]Palisano et al. (1997). [c]Eliasson et al. (2006). [d]Pennington, Virella, et al. (2013).

associated with slow speech. We operationally defined children with intelligibility scores of 80% or higher as having *mild* deficits and children with intelligibility scores below 80% as having *moderate–severe* deficits: Fifteen children were in the mild group, and 10 children were in the moderate–severe group. Note that we included children with CP who had a broad range of habitual intelligibility scores, including children with CP who did not have a clinical diagnosis of dysarthria. We included these children because recent work has found speech differences and reductions in speech intelligibility even for children with CP without a clinical diagnosis of dysarthria relative to a typically developing comparison group (Hustad et al., 2019, 2012). Thus, some of these children would be considered potential candidates for the slow speech strategy. In addition, those children with intelligibility scores on the high end for the mild group presented a unique experimental control, allowing us to examine the impact of the strategy on a full range of intelligibility levels. Examining this group also allowed us to consider the learning demands of the task in the absence of more significant motor impairment and the increased time demands that such motor impairments impose on implementing the slow speech strategy.

**Adult Listeners**

One hundred healthy adults participated as listeners in this study. Listeners were recruited from a university setting through public postings and social media. Listeners primarily consisted of undergraduate students. Two different listeners were randomly assigned to each child and each speaking condition. In particular, two listeners heard one child saying all sentences during the habitual speech condition, and two different listeners heard the same child saying all sentences in the slow speech condition: 25 children × 2 conditions × 2 listeners. Each listener heard only one child producing all stimulus items in a given condition. This listener–child assignment was used to control any learning effects that might occur with the same listener hearing the same child or same speech stimuli multiple times (Hustad, Oakes, & Allison, 2015). Presentation of stimulus items was randomized, and no two listeners heard the stimulus items presented in the same order. All listeners met the following inclusion criteria: (a) pass a pure-tone hearing screening administered via headphones at 25 dB HL at 250, 500, 1000, 4000, and 6000 Hz in both ears; (b) be between 18 and 45 years of age; (c) have no more than incidental experience listening to or communicating with persons having communication disorders; (d) be a native speaker of American English; and (e) have no identified language, learning, or cognitive disabilities per self-report. Listeners comprised 82 women and 18 men. The mean age of listeners was 24.6 (*SD* = 7.1) years.

## *Materials and Procedure*

As part of the larger longitudinal study, a standard research protocol consisting of speech, language, cognitive, and oral–motor assessments was administered to each participant at each visit by a research speech-language pathologist (SLP; see Hustad, Gorton, & Lee, 2010). Of interest to the current study were speech rate and intelligibility scores in two speech conditions: habitual speech and slow speech.

**Speech Conditions**

Each participant completed a structured speaking task in two speech conditions: habitual speech and slow speech. For both tasks, children were audio-recorded while repeating a list of sentences from the TOCS+ (Hodge, Daniels, & Gotzke, 2007), a developmentally appropriate set of speech stimuli that systematically vary in length. Stimuli consisted of sentences that ranged in length from two to seven words with 10 sentences of each stimulus length, for a total of 60 sentences. By eliciting the same set of stimuli from children, we were able to ensure that intelligibility scores reflected listeners' perception of target words relative to a known set of targets. Speaking tasks took place with the child seated at a table in a sound-attenuating suite next to a research SLP. Speech samples from children were recorded using a digital audio recorder (Marantz PMD 570, D&M Holdings, Inc.) at a 44.1-kHz sampling rate (16-bit quantization). A condenser studio microphone (Audio-Technica AT4040, Audio-Technica U.S., Inc.) was positioned next to each child using a floor stand and was located approximately 18 in. from the child's mouth. The level of the signal was monitored and adjusted on a mixer (Mackie 1202 VLZ, Mackie Designs, Inc.) to obtain optimized recordings and to avoid peak clipping. In the current study, not all children were able to produce all sentences of each length due to individual child motor, language, or cognitive factors. Table 2 shows the number of children producing sentences of each length for each speaking condition.

*Habitual speech task*. Adult recordings of each target stimulus sentence, along with an orthographic transcription and image depicting the sentence, were presented to children via a 12.9-in. Apple iPad Pro (see Figure 1 for an example). Children were asked to repeat what they heard

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

| Sentence length | Condition | Mild *n* = 15 | Moderate–severe *n* = 10 |
|---|---|---|---|
| Two words | Habitual | 15 | 10 |
| | Slow | 15 | 10 |
| Three words | Habitual | 15 | 10 |
| | Slow | 15 | 10 |
| Four words | Habitual | 15 | 10 |
| | Slow | 14 | 9 |
| Five words | Habitual | 15 | 9 |
| | Slow | 14 | 7 |
| Six words | Habitual | 15 | 8 |
| | Slow | 13 | 6 |
| Seven words | Habitual | 15 | 7 |
| | Slow | 14 | 6 |

**Figure 1.** Example of a display for a five-word utterance during the habitual speech condition.

Baby likes his new toy.

upon completion of the recorded adult model. All child productions were monitored in real time by a research assistant to ensure that speech samples were free from overlap with the model and free from extraneous noises.

*Slow speech task*. The goal of the slow speech task was for children to reduce their rate of speech by inserting pauses between words during production of sentences. To accomplish this goal, we used a structured task involving teaching, modeling, and verbal and visual cueing. This structured slow speech task was created using customized software designed specifically for the task and was presented to children on a 12.9-in. Apple iPad Pro. The software was preprogrammed with the same 60 TOCS+ sentences ranging in length from two to seven words that were included in the habitual speech condition. Sentences were presented in a grid of cells with one word in each cell (see Figure 2). Orthographic transcriptions of the full target sentence were always presented in the first cell of the row on the left side. To make the task more engaging and to help children with implementing slow speech, each cell to the right of the full sentence contained a picture that corresponded to the constituent spoken words in the sentence. Pictures appeared when each cell was touched. Children were instructed to touch a cell that would make the matching picture appear and then to say the word when they saw the picture (see Figure 3). For one participant, hand-over-hand was used for touching each cell due to the child's manual motor limitations (this child scored a 4 on the Manual Abilities Classification System). Children were instructed to pause for approximately 1 s before moving on to the next word in the sentence. Note that touching the cell first before saying the word created a slight natural pause in addition to the cued 1-s pause between each word.

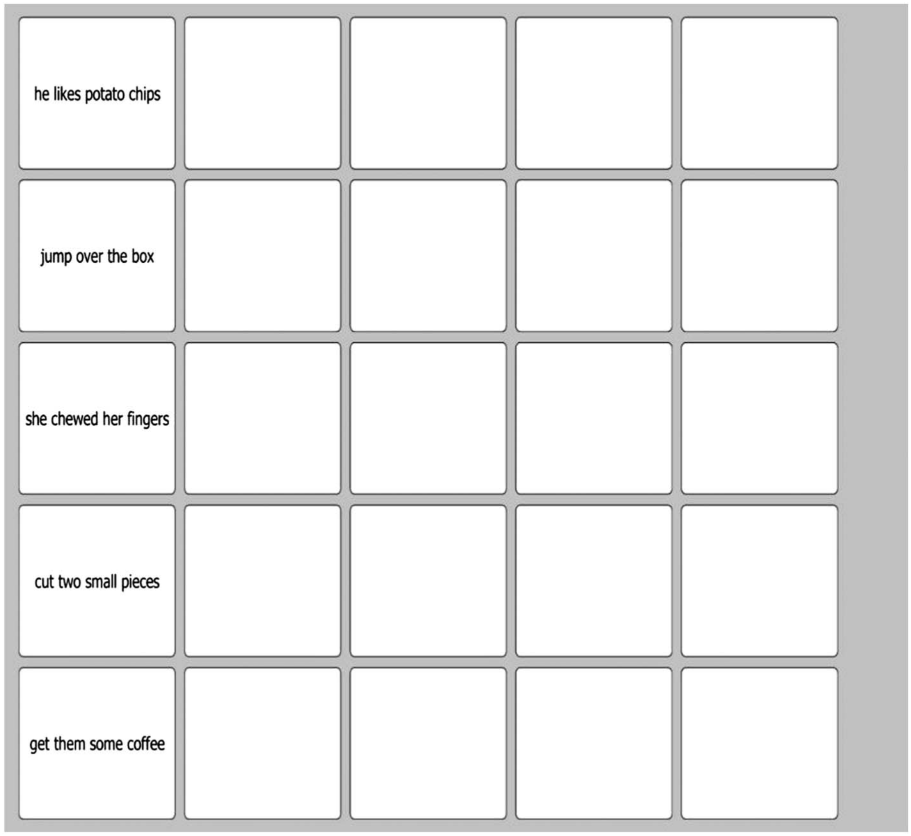
After explaining the task to the child, the clinician modeled the task using training sentences. These training sentences were not part of the original 60 TOCS+ sentences; they were created for the purpose of demonstrating the task to the children. For each training sentence, the clinician used the following protocol to demonstrate the task: (a) say the training sentence (e.g., "bake the pie"); (b) touch the first cell on the iPad app, activating a picture that corresponded to the first word in the sentence (i.e., a picture of a pie in the oven); (c) say the first word in the training sentence (i.e., "bake"); and (d) pause for approximately 1 s before continuing to the next word in the sentence. The clinician went through this protocol for each word in each of the training sentences. The child was then asked to repeat sentences in the same way as demonstrated by the clinician. During the training items, if the child did not complete the task as instructed or did not pause long enough between words, the clinician continued to model the strategy on the training sentences until the child correctly used the strategy. When the clinician was confident that the child understood the task and was correctly using the strategy during the training sentences, the clinician presented the testing items (i.e., the 60 TOCS+ sentences used in the habitual speech condition) to the child. For each testing item, the clinician said aloud the sentence while modeling the correct strategy. The child was then asked to imitate the model. Note that, unlike the habitual speech task that used a prerecorded adult model, in the slow speech task, the clinician produced a live model of the strategy. The clinician used perceptual judgment of the child's productions to determine if additional modeling was needed or the child needed to redo the test item. Coaching and encouragement from the clinician were given throughout the task. The slow speech task was administered immediately following the habitual speech task to ensure that children were familiar with the target sentences and that potential residual effects of reduced rate would not affect data gathered for habitual speech. All children were able to complete the slow speech task and required approximately 3–5 min to learn the task and successfully complete the practice items.

The first and third authors administered all data collection sessions. The first author developed the straightforward protocol and implementation approach. The third author was trained on the protocol by the first author, who ensured fidelity by observing initial data collection sessions. Both data collectors have extensive experience working with this clinical population. Note, however, as mentioned above, the habitual speech model was prerecorded and the elicitation task is part of a standard protocol used in the laboratory for our longitudinal work; the prerecorded habitual model was produced by a different female speaker from the two data collectors who administered the slow speech task.

### Intelligibility Outcomes

Digital audio recordings were transferred to a desktop computer and edited to remove extraneous noises and the prerecorded model or the SLP's model. Individual files were then created for each stimulus item produced by each child. Audio samples were peak amplitude normalized to ensure that maximum loudness levels of the recorded speech samples were the same across children and stimulus items while preserving the amplitude contours of the original productions. Speech stimuli were presented via in-house software to listeners seated in a sound-attenuating suite. The external speaker was calibrated on a regular

**Figure 2.** Example of a cueing display for four-word utterances. At the beginning of the task, all cells are blank. Children touch each cell, and a picture related to the prompted word appears in the cell.




basis by a research assistant to ensure the peak output level was 75 dB SPL from where listeners were seated.

Each listener was presented with all speech stimuli spoken by a single child for one speech condition. The in-house software randomized the presentation order of stimulus items for each listener. Each listener heard productions from only one condition. Listeners were instructed to provide orthographic transcriptions of each utterance—that is, to type what they thought the child had said. Two listeners provided transcriptions for each utterance for each child and each condition. In-house software scored each typed word as either correct or incorrect based on whether the listener transcription matched the target transcription phonemically. Misspellings and homonyms were accepted as correct, provided that all phonemes in the transcription matched the target. The total number of words transcribed correctly by each of the two listeners per child per condition were added together, then divided by the total number of words possible (across the two listeners), and multiplied by 100 to yield a percent intelligibility score for each child and each condition.

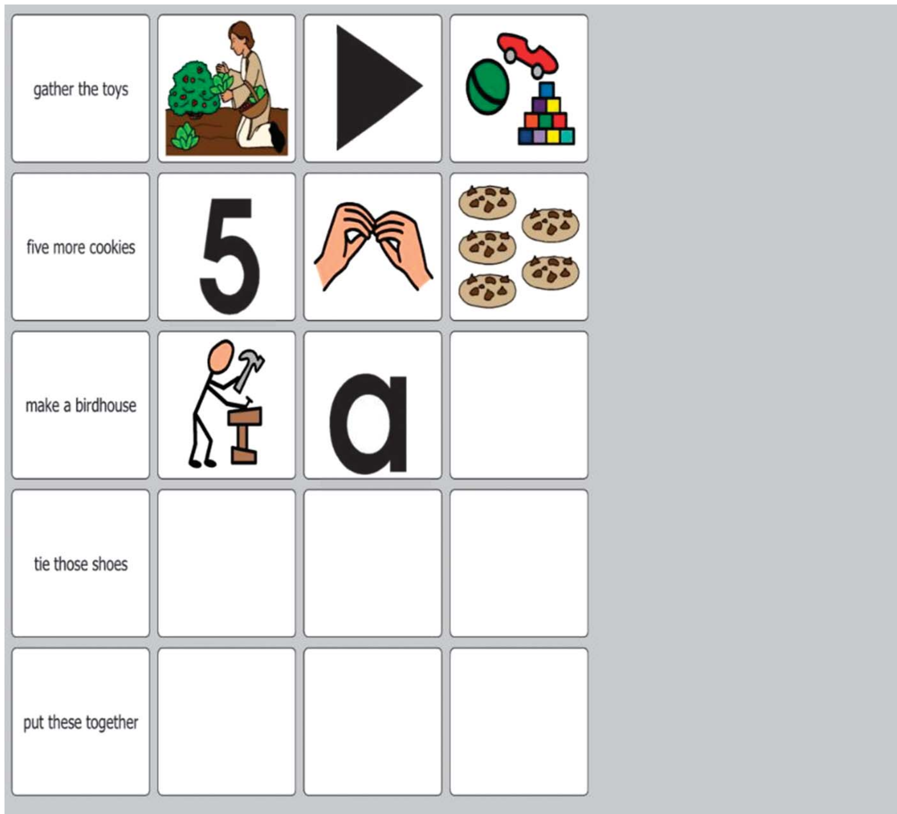
For each child and condition, we computed the difference in average intelligibility between the two listeners. In the habitual condition, the average difference between the two listeners was 1.5 percentage points (1.7 *SD*s) for the mild group and 4.4 percentage points (2.4 *SD*s) for the moderate–severe group. In the slow speech condition, the average difference was 2.0 percentage points (1.8 *SD*s) for the mild group and 2.9 percentage points (2.8 *SD*s) for the moderate–severe group. These values are well within the range of variability deemed acceptable following Lee, Hustad, and Weismer (2014).

We calculated interrater reliability of the average intelligibility scores for the two listeners used for each child by condition using the intraclass correlation coefficient (ICC) estimated with the irr R package (Version 0.84.1; Gamer, Jim, & Singh, 2019). We used a single-score, absolute-agreement, two-way random effects model, and we found strong agreement between the two listeners in all groups and conditions, $ICC_{Mild:Habit} = .84$, $ICC_{Mild:Slow} = .86$, $ICC_{ModSev:Habit} = .98$, and $ICC_{ModSev:Slow} = .99$.

### Rate Outcomes

Using the software Praat (Boersma & Weenink, 2019), research assistants trained in acoustic analysis marked the initiation and termination of each segmented and normalized two- to seven-word utterance. To accomplish this task, research assistants created text grids to align the spectrogram, waveform, phonemes, and words into one visible picture. The initiation and termination of each

**Figure 3.** Example of a cueing display for three-word utterances. Children touch each cell, and a picture related to the prompted word appears in the cell.



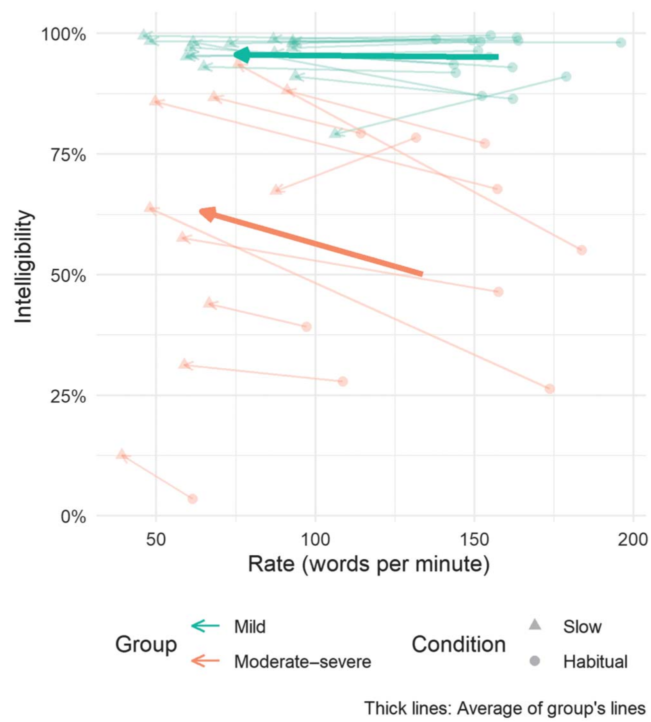

utterance were then marked. Sentence initiation was determined by locating the onset of audible or visible acoustic energy during production of the first phoneme of the sentence. Sentence termination was likewise determined by locating the offset of acoustic energy during production of the final phoneme of the sentence. Speech rate was calculated as words per minute (wpm) by adding together the total number of words a child spoke across all utterances, divided by the total duration in seconds (and inclusive of pauses) of all utterances multiplied by 60 s.

### *Research Design and Statistical Analysis*

Research questions of interest focused on (a) how rate changed when children used slow speech and the effect of utterance length on rate when children used slow speech by severity group and (b) how intelligibility changed when children used slow speech and the effect of utterance length on intelligibility when children used slow speech by severity group. We fit two sets of mixed models (one set for speech rate and one set for intelligibility) to estimate the effect of condition in each severity group. We estimated speech rate using a linear mixed model, and the fixed effects included group, condition, and a Group × Condition interaction. We analyzed data at the production level ($N$ = 2,570); that is, our data had a rate observation for each production by each child in the two conditions. We included by-child random intercepts to handle repeated measurements within each child and included by-child random condition effects to allow the condition effect to vary by child. We also included by-item random intercepts to account for repeated measurements of items across children. We estimated intelligibility with logistic regression using a generalized linear mixed model. Conventionally, logistic regression is used to model the number of successes in a given number of trials. In our case, the successes are the number of words correctly transcribed by the listeners, the trials are the number of words said by the child, and a child's intelligibility is the unobserved probability of success, estimated from the observed counts of successes and trials. We analyzed data at the sentence transcription level ($N$ = 5,140), so the number of trials for each transcription was the number of words in the sentence and the number of successes was the number of words correctly transcribed. As in the speech rate model, the model's fixed effects included group, condition, and a Group × Condition interaction, and we included by-child random intercepts, by-child random condition effects, and by-item random intercepts. Because there were two listeners per child, we added a by-listener random intercept to the intelligibility models to account for the nesting of listeners within children. Analyses were performed using the R programming language (Version 3.6.1; R Core Team, 2019). Mixed-effects models were fit using restricted maximum likelihood via the lme4 R package (Version 1.1.21; Bates, Mächler, Bolker, & Walker, 2015).

To evaluate the impact of utterance length on rate and intelligibility by severity group, we added utterance length as a categorical predictor, and its interactions with group, condition, and group-by-condition were added to the models' fixed effects. Thus, we fit a total of four models: rate with and without utterance length and intelligibility with and without utterance length. We only considered comparisons between consecutive lengths to be meaningful. For example, we were only interested in comparing the three-word utterances to two- and four-word utterances. Therefore, to estimate the effect of utterance length on speech rate, lengths were contrast-coded so that the difference in rate between consecutive levels could be estimated. These pairwise comparisons of consecutive levels and subsequent *p*-value adjustments for multiple tesing were performed using the emmeans R package (Version 1.4; Lenth, 2019). For the logistic regression models, we report effects using odds ratios (*OR*s) to convey the advantage of slow speech over habitual speech by utterance length.

**Figure 4.** Changes in rate (words per minute) and intelligibility (percentage of words identified correctly) from the habitual speech condition to the slow speech condition for children in the mild severity group (green) and the moderate–severe group (orange). Thick lines represent group means, thin lines represent individual children, and arrows are used to visualize the change from the habitual condition to the slow condition.




## Results

### *Impact of Slow Speech Strategy on Speech Rate*

Figure 4 shows the change in speech rate by speaking condition (slow and habitual) within each severity group. Descriptive results suggest that all children had a reduction in speech rate when implementing the slow speech strategy. This effect can be observed in Figure 4 where all of the lines point to a slower rate.

The slow speech condition yielded a statistically significant decrease in speech rate for both groups. In the mild group, children used an average habitual rate of 158 wpm, and this rate decreased on average by 82 wpm, $SE$ = 7.7, $t(22.9) = -10.71$, $p < .001$, in the slow speech condition. In the moderate–severe group, children used an average habitual rate of 135 wpm, and this rate decreased on average by 68 wpm, $SE$ = 9.4, $t(23.2) = -7.19$, $p < .001$, in the slow speech condition. The moderate–severe group had a slower speech rate on average in both conditions. This group difference was significant in the habitual condition, $\text{diff}_{\text{Mild−ModSev}}$ = 23 wpm, $SE$ = 10.7, $t(23.0) = -2.10$, $p$ = .047, but the smaller difference in the slow condition was not statistically clear, $\text{diff}_{\text{Mild−ModSev}}$ = 8 wpm, $SE$ = 7.5, $t(23.1) = -1.09$, $p$ = .29. Table 3 reports complete regression results.

There was considerable variability in habitual speaking rates among children within each group, especially for children in the moderate–severe group. For children in the moderate–severe group, habitual speech rates ranged from 61 to 184 wpm. The five children with the slowest habitual speech rates were all from the moderate–severe group. Two of these children (P13 and P14) had habitual speech rates below 100 wpm. Overall, the floor for speech rates was lower in the moderate–severe group; the slowest children overall were from this group. The ceiling for speech rates, however, was not lower for this group. Indeed, the second fastest child overall (P18) was from the moderate–severe group.

### *Impact of Utterance Length on Speech Rate*

Figure 5 shows the change in rate by utterance length within severity group. Descriptive results suggest that children in both groups had a reduction in speech rate when implementing the slow speech strategy for all utterance lengths. Inferential statistics revealed a statistically significant reduction in speech rate in the slow speech condition relative to the habitual speech conditions for all utterance lengths for both the mild group and the moderate–severe group.

In the habitual speech condition, there was a tendency for children to speak longer utterances with a faster speech rate. Table 4 reports the estimated marginal mean speech rate for each group, speaking condition, and

**Table 3.** Regression summary for the Group × Condition mixed-effects models.

| Predictors | Rate (linear regression) | | | | | Intelligibility (logistic regression) | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Estimate | *SE* | 95% CI | *t* | *p* | *OR* | 95% CI (*OR*) | *z* | *p* |
| Intercept (habitual, mild) | 157.95 | 7.03 | [144.16, 171.73] | 22.45 | < . 001 | 36.65 | [18.88, 71.13] | 10.64 | < .001 |
| Moderate–severe | −22.59 | 10.75 | [−43.66, −1.53] | −2.10 | .047 | 0.03 | [0.01, 0.07] | −7.24 | < .001 |
| Slow | −82.28 | 7.68 | [−97.34, −67.22] | −10.71 | < .001 | 1.08 | [0.69, 1.71] | 0.35 | .727 |
| Moderate–Severe × Slow | 14.40 | 12.17 | [−9.46, 38.26] | 1.18 | .249 | 2.04 | [1.03, 4.06] | 2.04 | .042 |
| **Random effects** | | | | | | | | | |
| $\sigma^2$ (residual variance) | 467.25 | | | | | — | | | |
| $\tau_{00}$ (intercept variance) | 684.06 Child<br>199.76 Item | | | | | 1.49 Child<br>0.47 Item<br>0.03 Listener | | | |
| $\tau_{11}$ (slope variance) | 868.22 ChildSlow | | | | | 0.61 ChildSlow | | | |
| $\rho_{01}$ (correlation) | −.80 Child, ChildSlow | | | | | −.39 Child, ChildSlow | | | |
| Observations | 2,570 children's productions<br>25 children<br>60 items | | | | | 5,140 listener transcriptions<br>25 children<br>60 items<br>100 listeners | | | |

*Note.* CI = confidence interval; *OR* = odds ratio.

utterance length. For the mild group, the estimated marginal speech rate for the habitual condition was 123 wpm, *SE* = 7.6, for two-word utterances and 183 wpm, *SE* = 7.5, for seven-word utterances. Three-word utterances were significantly faster than two-word utterances, $\text{diff}_{3-2}$ = 21.5, *SE* = 4.54, $p < .001$; four-word utterances were significantly faster than three-word utterances, $\text{diff}_{4-3}$ = 13.5, *SE* = 4.15, *p* = .006; and six-word utterances were significantly faster than five-word utterances, $\text{diff}_{6-5}$ = 12.6, *SE* = 3.90, *p* = .007. Rate differences were not statistically clear for five-word utterances, $\text{diff}_{5-4}$ = 5.3, *SE* = 4.07, *p* = .60, or seven-word utterances, $\text{diff}_{7-6}$ = 7.3, *SE* = 3.68, *p* = .20, although the rate differences were positive, following the trend of the other utterance lengths.

**Figure 5.** Changes in rate (words per minute) and intelligibility (percentage of words identified correctly) from the habitual speech condition to the slow speech condition by utterance length for children in the mild severity group (green) and the moderate–severe group (orange). Thick lines represent group means, thin lines represent individual children, and arrows are used to visualize the change from the habitual condition to the slow condition. Points without lines are cases where a child completed the task for the utterance length in only one of the speech conditions. These points do not contribute to the plotted means.

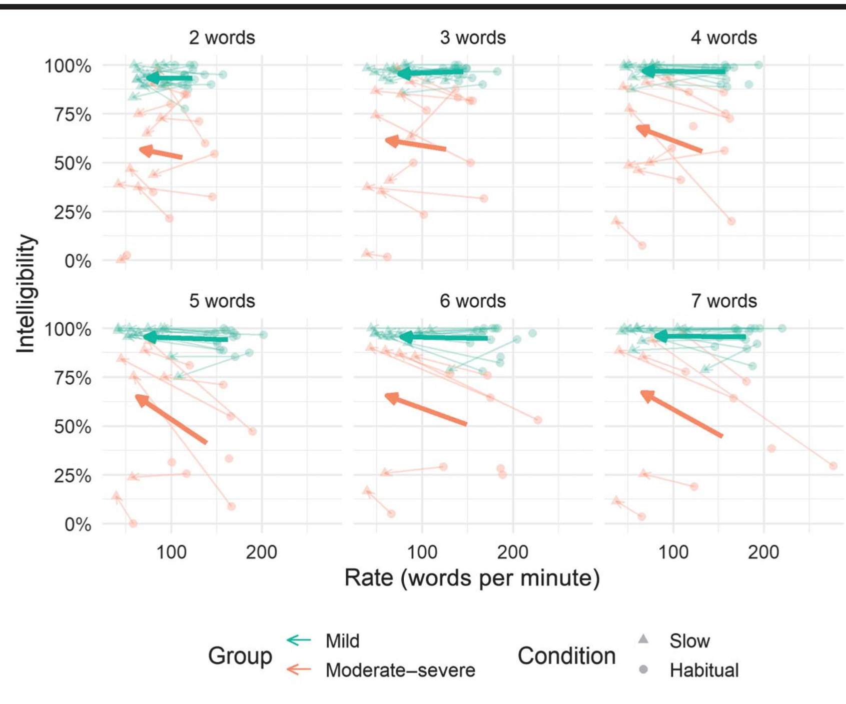


**Table 4.** Estimated marginal means for the Group × Condition × Length mixed-effects models.

| Utterance length | Habitual speech | | | Slow speech | | |
|---|---|---|---|---|---|---|
| | Estimate | *SE* | 95% CI | Estimate | *SE* | 95% CI |
| Mild: rate | | | | | | |
| 2 | 123 | 7.6 | [108, 139] | 75 | 5.7 | [63, 86] |
| 3 | 145 | 7.5 | [129, 160] | 74 | 5.6 | [63, 85] |
| 4 | 158 | 7.5 | [143, 173] | 69 | 5.5 | [58, 80] |
| 5 | 163 | 7.5 | [148, 179] | 73 | 5.5 | [62, 84] |
| 6 | 176 | 7.4 | [161, 191] | 75 | 5.5 | [64, 86] |
| 7 | 183 | 7.5 | [168, 199] | 85 | 5.5 | [74, 96] |
| Moderate–severe: rate | | | | | | |
| 2 | 112 | 9.0 | [93, 130] | 67 | 6.7 | [54, 81] |
| 3 | 126 | 9.0 | [108, 144] | 61 | 6.5 | [48, 74] |
| 4 | 130 | 8.9 | [112, 149] | 62 | 6.5 | [48, 75] |
| 5 | 139 | 9.0 | [121, 158] | 65 | 6.6 | [51, 78] |
| 6 | 155 | 9.0 | [136, 173] | 61 | 6.7 | [47, 74] |
| 7 | 164 | 9.1 | [146, 183] | 69 | 7.0 | [55, 83] |
| Mild: intelligibility | | | | | | |
| 2 | 97% | 1.2 | [94, 99] | 97% | 1.2 | [93, 99] |
| 3 | 98% | 0.8 | [96, 99] | 97% | 1.1 | [94, 99] |
| 4 | 97% | 1.0 | [95, 99] | 97% | 1.1 | [94, 99] |
| 5 | 97% | 1.1 | [94, 98] | 98% | 0.9 | [95, 99] |
| 6 | 96% | 1.3 | [92, 98] | 98% | 0.9 | [95, 99] |
| 7 | 98% | 0.8 | [96, 99] | 98% | 0.7 | [96, 99] |
| Moderate–severe: intelligibility | | | | | | |
| 2 | 55% | 11.0 | [34, 75] | 62% | 10.3 | [41, 80] |
| 3 | 56% | 10.6 | [35, 75] | 65% | 9.6 | [44, 81] |
| 4 | 54% | 10.4 | [34, 73] | 73% | 8.1 | [55, 86] |
| 5 | 38% | 9.9 | [21, 58] | 69% | 8.8 | [50, 84] |
| 6 | 40% | 10.1 | [23, 61] | 63% | 9.7 | [43, 79] |
| 7 | 45% | 10.5 | [27, 66] | 71% | 8.8 | [51, 85] |

*Note.* CI = confidence interval.

A similar pattern of longer utterances being produced at faster speech rates for the habitual speech condition was observed for the moderate–severe group. The estimated marginal mean speech rate in the habitual condition was 112 wpm, $SE = 9.0$, for two-word utterances and 164 wpm, $SE = 9.1$, for seven-word utterances. Three-word utterances were significantly faster than two-word utterances, $\text{diff}_{3-2} = 14.2$, $SE = 4.58$, $p = .01$, and six-word utterances were significantly faster than five-word utterances, $\text{diff}_{6-5} = 15.4$, $SE = 4.36$, $p = .002$. The remaining rate differences were not statistically clear: four-word utterances, $\text{diff}_{4-3} = 4.4$, $SE = 4.19$, $p = .78$; five-word utterances, $\text{diff}_{5-4} = 8.8$, $SE = 4.25$, $p = .17$; or seven-word utterances, $\text{diff}_{7-6} = 9.6$, $SE = 4.40$, $p = .13$. As in the mild group, all the consecutive rate differences were numerically positive, but not all of the individual steps were statistically reliable.

In the slow speech condition, the estimated marginal speech rates ranged from 61 to 85 wpm across the two groups of children. There were not any statistically clear differences in speech rate for consecutive changes in utterance length, all *p*s > .05. These results are as expected. Children were instructed to pause for approximately 1 s between words in the slow condition, and as a result, their speaking rates normalized to approximately 70 wpm, regardless of severity group.

### *Impact of Slow Speech Strategy on Speech Intelligibility*

Figure 4 also shows the change in intelligibility by condition within each severity group. Descriptive results suggest an improvement in speech intelligibility for the slow speech condition in the moderate–severe group but no change in speech intelligibility for the mild group.

There was a statistically significant increase in speech intelligibility for the slow speech condition for children in the moderate–severe group. When speaking with habitual rate, children in the moderate–severe group had an estimated average intelligibility of 47.9%. After implementing slow speech, the average intelligibility increased to 67.1%, $z = 3.04$, $p = .002$. There was not a statistically clear change in intelligibility between the two conditions for the mild group. Under a habitual speech rate, children in the mild group had an estimated average intelligibility of 97.3%. With slow speech, the estimated average intelligibility was 97.5%, which was not a significant change from habitual speech, $z = 0.35$, $p = .73$. Table 3 reports complete regression results.

As with the speech rate results, there was considerable variability among children for both groups. In the moderate–severe group, habitual intelligibility ranged from 3.4% to 79.6%. Three children (P04, P17, and P18) in this group had improvements in intelligibility greater than 10 percentage points, and one child (P11) had a decrease in intelligibility of 9.7 percentage points for the slow speech task. In the mild group, intelligibility prior to treatment ranged from 88.0% to 99.6%. One child (P10) in this group had a 10–percentage point improvement in intelligibility for the slow speech task. One child (P09) had 10.1–percentage point decrease in intelligibility for the slow speech task.

### *Impact of Utterance Length on Speech Intelligibility*

Figure 5 also shows change in intelligibility by utterance length within severity group. Descriptive results suggest that children in the moderate–severe group showed a greater improvement in speech intelligibility for longer sentences; however, there was considerable variability for children within this group. For example, for two-word utterances, four of 10 children showed decreased intelligibility in the slow speech condition (falling arrows), but in the seven-word utterances, all six children with data from both conditions showed increased intelligibility when using slow speech (rising arrows).

Children in the mild group did not show any significant changes in their average speech intelligibility between the two speaking conditions for utterances of any length. Table 4 reports the estimated marginal mean intelligibility for each group, condition, and utterance length. For the mild group, the estimated marginal intelligibility means for each sentence length ranged from 96.2% (six-word) to 98.1% (three-word) in the habitual speech condition and ranged from 96.9% (two-word) to 98.0% (seven-word) in the slow speech condition.

In contrast, children in the moderate–severe group on average showed significant improvements in intelligibility in the slow speech condition for most sentence lengths. The estimated marginal intelligibility means for each sentence length ranged from 37.7% (five-word) to 55.8% (three-word) in the habitual speech condition and from 62.4% (two-word) to 73.0% (four-word) in the slow speech condition. These ranges do not overlap; the highest estimated average intelligibility in habitual speech is less than the lowest average in slow speech. The *OR* of slow speech intelligibility over habitual speech intelligibility was not statistically clear for two-word utterances, $OR_2 = 1.33$, $p = .34$, or three-word utterances, $OR_3 = 1.44$, $p = .19$. The advantage of slow speech over habitual speech was significant for longer utterances: four words, $OR_4 = 2.32$, $p = .003$; five words, $OR_5 = 3.70$, $p < .001$; six words, $OR_6 = 2.49$, $p = .001$; and seven words, $OR_7 = 2.87$, $p < .001$. Intelligibility in the slow speech condition was numerically greater than that of the habitual speech condition for all utterance lengths—all *OR*s are greater than 1—but the estimated marginal improvement was only statistically significant for utterances of four or more words in length. In Figure 5, this effect can be seen by observing how all of the group average arrows for the moderate–severe group move upward. Results indicate that the benefit of slow speech by utterance length was more statistically reliable at the longer utterance lengths.

## Discussion

The purpose of this study was to examine whether children with CP could manipulate their rate of speech and whether reducing rate of speech would improve speech intelligibility. We were also interested in investigating the effect of severity (as determined by habitual speech intelligibility) and the effects of utterance length on rate and intelligibility. We divided children into two groups: a moderate–severe group of children with habitual speech intelligibility scores below 80% and a mild group of children with habitual speech intelligibility scores above 80%. There were two key findings from this study. First, all children, regardless of severity group, were able to reduce their rate of speech when implementing the slow speech strategy. There was not a differential effect of utterance length on speech rate in the slow speech condition: Children used a similar rate for utterances of any length. Second, only children in the moderate–severe group showed an improvement in intelligibility when implementing the slow speech strategy. There was a greater improvement in intelligibility with slow speech for longer sentences than for shorter ones, with considerable individual variability.

### *Change in Speech Rate With the Slow Speech Strategy*

Implementation of the slow speech strategy successfully reduced rate of speech for both groups of children: those with mildly reduced habitual intelligibility scores and those with moderately to severely reduced habitual intelligibility scores. This finding is similar to results from adult treatment studies showing that adults with dysarthria are capable of producing changes in rate of speech following simple instruction and cueing (Hustad & Sassano, 2002; McHenry, 2003; Pilon et al., 1998; Yorkston et al., 1990). The average percentage reduction in speech rate (100% × [habitual − slow] / habitual) was 52% for the mild group and 49% for the moderate–severe group, suggesting that the strategy had a similar relative impact on rate for both groups of children. There was considerable variation across children, regardless of group. For example, the range of rate reduction was 33%–76% (55% median) for the mild group and 31%–72% (43% median) for the moderate–severe group. Generally, children with faster habitual speech rates made larger percentage reductions when they implemented the slow speech strategy, a finding that follows from the nature of the slow speech task, which required children to repeat sentences after a model and make 1-s pauses between words.

When children implemented slow speech, their rate of speech was consistent, regardless of utterance length and regardless of group membership. This finding suggests that the slow speech strategy was effective at inducing a uniform speaking rate across utterances. The particular approach that we used involved coaching from a clinician and was errorless in the sense that children were provided feedback and prompting until they were able to use the strategy successfully. Children learned quickly and were able to participate in the slow speech task with relatively minimal instruction. Children in this study had a variety of ability profiles including intellectual disability, receptive language impairment, executive function deficits, and a range of gross and fine motor limitations. However, all children were able to use their hands and arms to point, and none of the children had severe gross motor or manual function limitations as indicated by the Gross Motor Classification System and the Manual Abilities Classification System levels. Despite ability profile, every child was able to reduce speech rate when implementing the slow speech strategy. Although children learned the strategy quickly and easily, it is unclear how well the slow speech strategy as implemented with an iPad would generalize to more spontaneous speaking tasks. Other external pacing tools may need to be considered or developed that would be more applicable and valid for spontaneous speech production. Studies are needed to investigate learning and the feasibility of such a strategy in different communication contexts. In addition, the question of whether speaking rate findings from this study are specific to the rate reduction approach that we used or whether the same result might be found with other rate reduction strategies such as pacing boards or verbal cues to use "slow speech" is unknown. This would be an interesting topic for future investigation. However, results of this study are promising in that they suggest that children with a range of ability profiles were able to reduce their rate.

With regard to habitual speech rate, one interesting finding that is consistent with other literature on speech rate in children with CP is that children tended to produce longer utterances with faster speech rates. This result was true for both groups of children in this study and is consistent with findings from a recent study examining longitudinal growth in speech rate among children with CP (Darling-White et al., 2018). The finding that, as a result of the slow speech strategy, children slow down by the same amount regardless of habitual speech rate suggests that it may be an effective approach to help children slow down multiword utterances of varying lengths.

Collectively, findings related to the implementation of the slow speech strategy suggest that children were able to modify their speech rate using a structured task and that the resultant rate of speech was generally consistent among children and among utterances of different lengths, regardless of severity. Our findings indicate the task was an effecive approach for reducing rate and may hold clinical potential as a tool for rate reduction in children in further clinical studies.

## *Change in Intelligibility*

Only children in the moderate–severe group showed an improvement in speech intelligibility when implementing the slow speech strategy; children in the mild group did not improve. This finding is not surprising given that children with greater reductions in habitual intelligibility had more room for positive change in intelligibility. This result is consistent with older published guidelines for children (Strand, 1995) and findings from adult treatment studies showing that adults with more severe dysarthria and therefore lower speech intelligibility had greater gains in intelligibility when rate was reduced via interword pauses (Hustad & Sassano, 2002; Pilon et al., 1998). The average percentage point improvement in speech intelligibility was 11.1 for the moderate–severe group. There was, however, variation across children. For example, intelligibility improvements from slow speech ranged from −9.73 (decreased intelligibility) to 35.1 (7.97 median) for the moderate–severe group.

When children in the moderate–severe group implemented slow speech, there was a greater improvement in intelligibility for longer sentences than for shorter ones, with considerable individual variability among children. In particular, intelligibility was significantly higher in the slow speech condition than in the habitual condition for utterances that were four or more words in length. For the two- to three-word sentences, there was an intelligibility advantage in the slow speech condition, but it was not statistically significant. There are several explanations for this finding. First, there may have been differences in cognitive load for the production of longer versus shorter utterances. In addition, longer utterances tend to be more complex to produce, and therefore, production may deteriorate to a greater extent for children with more significant speech motor involvement. Findings from the habitual speech condition (see Table 4) indicate that intelligibility differences were evident between longer and shorter utterances, with intelligibility being considerably worse for longer utterances than for shorter ones produced habitually. At the same time, we found that longer utterances were produced with faster speech rate than shorter utterances for habitual speech. Producing speech more rapidly may result in more coarticulation, reduced coordination as the utterance proceeds, increasingly blurred word boundaries, and less time for listeners to process the speech signal, all of which may lead to more difficulty decoding the acoustic signal for listeners and thus resulting in lower intelligibility. However, when speech rate is controlled via the slow speech strategy and children produce all utterances at a uniform rate, as was observed in this study, intelligibility improved dramatically for longer utterances. This improvement is relative to both habitual speech where a mean improvement of up to 26 percentage points was observed (seven-word utterances) and relative to shorter utterances produced in the slow speech condition where a mean improvement of up to 9 percentage points was observed (two- vs. seven-word utterances).

Although children in the mild group had a significant reduction in speech rate following use of the strategy, reducing rate of speech had no effect on speech intelligibility for this group as a whole. For all but three children, the changes in intelligibility were relatively small, between −1.9 and 1.8 percentage points. One child made a mild gain of 4.4 percentage points. Two children made large changes in intelligibility with a reduced speech rate, one in a negative direction and one in a positive direction. Individual differences are difficult to explain; our findings suggest that children with habitual intelligibility above 80% would likely not be good candidates for the use of slow speech to increase intelligibility.

## *Limitations and Future Directions*

There were several limitations to this study. We had a relatively small number of children. In addition, over half of the children in the current study had habitual intelligibility scores above 80%. By including children with mildly reduced habitual intelligibility scores, we were able examine the feasibility of the task and examine the learning demands of the task in the absence of more severe motor impairment. Results from the current study suggest that use of slow speech as implemented in a structured clinical task was successful at reducing speech rate in children with CP regardless of their habitual intelligibility. However, given that children with habitual intelligibility scores above 80% did not show an improvement in intelligibility with the slow speech strategy, this technique does not seem to be viable for these children.

This study was designed to evaluate the preliminary feasibility of using a speech supplementation strategy to reduce rate and improve intelligibility in children with CP. Therefore, findings should be interpreted cautiously and in the context of the specific parameters of the strategies described in this article, which include direct and errorless teaching, modeling, and cueing. In this study, we used a highly structured speech task in a controlled setting. Speech samples were obtained from a repetition task. Data from a more ecologically valid task involving spontaneous speech in a real communication situation may yield different findings with regard to successful implementation of slow speech and with regard to the effects of slow speech on intelligibility and speech rate.

In the current study, the slow speech condition always followed the habitual speech condition. As previously mentioned, we did this to ensure that children were familiar with the target sentences and that potential residual effects of reduced rate would not affect data gathered for habitual speech. However, familiarization and fatigue during the slow speech condition may have occurred. Future studies may want to consider presentation order as a factor in analyses. Additionally, we examined measures of speech rate and intelligibility before and after only one teaching session. Studies are needed that examine the effectiveness of these strategies and to determine whether further intelligibility and rate changes might occur over time as a child uses the strategy.

The current study did not examine the effects of rate reduction on the naturalness of speech. It is well known that rate reduction reduces the naturalness of speech (Logan, Roberts, Pretto, & Morey, 2002; Yorkston et al., 1990). For some speakers with dysarthria, the gain in intelligibility is worth the cost to speech naturalness; however, future research is needed to examine this further.

In this study, we did not examine whether there were changes in acoustic production features associated with reducing rate of speech. Thus, we do not know the specific sources of change that may be responsible for our findings. Such information is critical to advance our understanding of not only whether a strategy works but also why and how it works. Future studies should examine differences in acoustic measures, such as vowel space, range of formant movement, and temporal features of speech to quantify how these measures change with slow speech and how these changes might contribute to speech intelligibility. Further work might also shed light on variables that reduce intelligibility in the speech signal to identify what features are sensitive to changes in speech rate. In turn, this information could refine our ability to identify appropriate candidates for the strategy. For example, deliberate interword pauses may clarify word boundaries and prevent words from blending together, but if a speaker does not show unnatural coarticulation at word boundaries, then improving word boundaries with pausing will likely not improve intelligibility.

Finally, during both speech conditions, recording levels of the speech signal were adjusted online. Therefore, the speech signal was maximized for any child who spoke quietly during the task. It is possible that this amplitude normalization could have had an effect on intelligibility by making the signal louder when played for listeners. However, in the current study, children varied in their loudness, and we normalized samples to control for that variability. The examination of the effects of loudness on intelligibility was beyond the scope of this study, and more research is needed to explore this important topic.

### *Clinical Implications*

There are several important clinical implications from this study. First, children with CP, even those with severe speech deficits and concomitant intellectual and motor impairments, were able to manipulate their speech production to slow their rate of speech following simple instruction and verbal and visual cueing. Findings suggest that this speech manipulation strategy may be most beneficial for children with dysarthria who have moderately to severely reduced habitual intelligibility when producing sentences that are more than four words in length. Thus, children who may be candidates for further investigation of a slow speech approach to intervention may be those who speak in longer utterances and who have at least moderate intelligibility deficits. Future studies should seek to further examine the clinical feasibility of slow speech for children with intelligibility deficits.

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