JSLHR

Research Article

Acoustic and Perceptual Consequences of Speech Cues for Children With Dysarthria

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Purpose: Reductions in articulatory working space and vocal intensity have been linked to intelligibility deficits in children with dysarthria due to cerebral palsy. However, few studies have examined the outcomes of behavioral treatments aimed at these underlying impairments or investigated which treatment cues might best facilitate improved intelligibility. This study assessed the effects of cues targeting clear speech (i.e., "Speak with your big mouth") and greater vocal intensity (i.e., "Speak with your strong voice") on acoustic measures of speech production and intelligibility.
Method: Eight children with spastic dysarthria due to cerebral palsy repeated sentence- and word-level stimuli across habitual, big mouth, and strong voice conditions. Acoustic analyses were conducted, and 48 listeners completed orthographic transcription and scaled intelligibility ratings.
Results: Both cues resulted in significant changes to vocal intensity and speech rate although the degree of change varied by condition. In a similar manner, perceptual analysis revealed significant improvements to intelligibility with both cues; however, at the single-word level, big mouth outperformed strong voice.
Conclusion: Children with dysarthria are capable of changing their speech styles differentially in response to cueing. Both the big mouth and strong voice cues hold promise as intervention strategies to improve intelligibility in this population.
Supplemental Material: https://doi.org/10.23641/asha.5116843

This special issue contains selected papers from the March 2016 Conference on Motor Speech held in Newport Beach, CA.

It is estimated that 40% to 90% of children with cerebral palsy (CP) exhibit motor speech disorders that negatively affect speech intelligibility (Kennes et al., 2002; Mei, Reilly, Reddihough, Mensah, & Morgan, 2014). Although dysarthria differs in its severity and presentation across children, it can have considerable detrimental effects upon their psychological, social, and educational outcomes (Boyle, Decoufle, & Yeargin-Allsopp, 1994; Kennes et al., 2002; Mei et al., 2014; Nadeau & Tessier, 2009). Maximizing speech intelligibility is therefore a common intervention goal for children with dysarthria due to CP (henceforth, *children with dysarthria*). Yet there have been few studies focused on the outcomes of behavioral speech intervention or examinations of the relative success of various cues for eliciting speech modifications aimed at enhancing intelligibility. Hence, it is necessary to evaluate empirically the relationship between such cues and their consequences for intelligibility in children with dysarthria, a population in critical need of evidence-based behavioral speech interventions (Pennington, Miller, & Robson, 2009). The current study focused on this issue, comparing two approaches to enhancing speech intelligibility in children with dysarthria. It aimed to determine if these techniques result in speech modifications (as measured acoustically) and increased intelligibility (measured perceptually).

The salient speech characteristics of dysarthria in children with CP vary considerably from child to child. However, reductions in vowel space area, speech rate, and vocal intensity are commonly observed (DuHadway & Hustad, 2012; Fox & Boliek, 2012; Higgins & Hodge, 2002; Hustad, Gorton, & Lee, 2010; Lee & Hustad, 2013). Perceptually, decreased overall intelligibility (DuHadway & Hustad, 2012; Lee, Hustad, & Weismer, 2014) as well as vowel intelligibility (Levy, Leone, et al., 2016) and accuracy (Byrne, 1959) have also been noted. Important to the development of treatment approaches, it appears that articulatory subsystem deficits are a major contributor to the intelligibility reductions experienced by children with dysarthria. Therefore, treatments that focus on improved articulation—or that have improved articulation as a by-product of the approach —appear to be logical primary targets for intervention

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Editor: Yana Yunusova
Associate Editor: Adam Buchwald
Received June 28, 2016
Revision received September 16, 2016
Accepted January 9, 2017
https://doi.org/10.1044/2017_JSLHR-S-16-0274

Disclosure: *The authors have declared that no competing interests existed at the time of publication.*

(Lee et al., 2014). Treatment should also involve relatively straightforward, child-friendly cues that are easy to understand and apply—in particular because many children with CP have multiple disabilities, including learning disability (Ashwal et al., 2004; Beckung & Hagberg, 2002).

Studies examining the outcomes of speech treatment for children with dysarthria have commonly focused on multiple subsystems to achieve changes in speech production (e.g., Levy, 2014; Levy, Ramig, & Camarata, 2012; Pennington, 2008; Pennington, Miller, Robson, & Steen, 2010; Pennington et al., 2013). For example, Pennington et al.'s (2010, 2013) systems-based approach involved stabilizing children's respiration and phonation, syllables per breath or phrase length, and speech rate. Children practiced using slow speech with coordinated breath supply and phonation, and high-intensity treatment followed motor learning principles. Through these approaches, children experienced improved intelligibility and enhanced articulatory precision, suggesting that intervention targeting multiple subsystems may produce positive outcomes for children with dysarthria.

So-called "global" approaches to intervention, in contrast, focus on a single instruction or cue (e.g., "speak clearly"). For children with dysarthria, especially younger children and those with concurrent disabilities, multiple instructions may be expected to increase cognitive load and have the potential to limit the generalizability of treatment effects. Instead, simple directions focused on a single task may be advantageous for those whose ability to follow directions might be limited (Nugent & Mosley, 1987). In terms of research, the use of a single cue enables direct comparison with other single cues (e.g., investigation of the effects of loud versus slow speech) and may ultimately shed some light on specific mechanisms underpinning the changes.

The few studies that have investigated the outcomes of speech treatment for children with dysarthria using a global approach have focused on the single cue *loud,* delivered with the Lee Silverman Voice Treatment (L. Ramig & Fox, 2010). These studies have shown promising results (Boliek & Fox, 2014; Fox & Boliek, 2012; Levy, 2014; Levy et al., 2012) with listeners preferring posttreatment utterances to pretreatment (Fox & Boliek, 2012) and providing higher intelligibility ratings following treatment (Levy et al., 2012). It appears that for children with dysarthria the use of a global cue is likely to be beneficial, although which type of cue facilitates the greatest improvements in speech intelligibility is unknown.

The current study focused on the consequences of two global cues developed specifically for use with children with dysarthria. Termed *big mouth* and *strong voice,* these cues are a child-friendly adaptation of existing techniques of clear and loud speech, respectively, both of which have commonly been shown to improve intelligibility in adults with dysarthria (e.g., Tjaden, Richards, Kuo, Wilding, & Sussman, 2014). Cues aimed at eliciting clear and loud speech were selected for comparison for a number of reasons. First, in children with dysarthria, articulatory impairment has been shown to account for a considerable proportion of the variance in intelligibility scores (Lee et al., 2014). Indeed, this finding led Lee et al. (2014) to conclude that "evidence supports primary attention to the articulatory subsystem in the case of both children and adults when the goal is to improve speech intelligibility" (p. 1676). In terms of a global speech prompt, clear speech has been shown to result in significant changes to articulation as evidenced by maximized nonperipheral and peripheral vowel space areas, concurrent with improved intelligibility (Lam & Tjaden, 2013; Tjaden, Lam, & Wilding, 2013). It is thought that the articulatory care taken by the speaker when using this speech style enhances the acoustic information available to the listener, especially when the speech signal is perturbed (Smiljanić & Bradlow, 2009). Second, prior studies that have used a loud cue have also been shown to result in improvements in acoustic measures and preference for posttreatment stimuli in children with dysarthria (Fox & Boliek, 2012). Furthermore, improvements to articulation are also commonly observed as a consequence of louder speech (Levy et al., 2012; Sapir, Spielman, Ramig, Story, & Fox, 2007). Therefore, it appears likely that cues to speak with clear speech or a loud voice would have beneficial effects on intelligibility in children with dysarthria.

The present study compared the use of these two global speech manipulation strategies, big mouth and strong voice, on acoustic and perceptual outcomes in eight children with spastic dysarthria due to CP. It was not evident that these children with motor limitations would successfully modify their speech. Thus, we investigated if the big mouth and strong voice cues would, at the group level, elicit speech production changes as measured by acoustic analysis. We further examined if implementation of these cues would result in significant increases in the children's intelligibility as measured by listeners' percentage of words correct (PWC; in single word transcription) and visual analogue scaling (in both single words and sentences). Last, we aimed to determine if a relationship would exist between the degree of acoustic and perceptual change, potentially shedding light on modifications in speech production responsible for any intelligibility gains.

It was hypothesized that the children would be able to change their speech styles in response to both big mouth and strong voice cues, yielding acoustically measurable differences in their speech production (i.e., duration, sound pressure level [SPL], and first and second formant frequencies [F1/F2])[1] and increasing their intelligibility at the

[1]Changes in F1 and F2 were expected for the big mouth condition as clear speech is associated with greater vowel space area (Ferguson & Kewley-Port, 2002). Speech in response to instructions to "overenunciate" is characterized by significant change in spectral measures compared with speech following instructions to speak clearly or to speak to someone with a hearing loss (Lam & Tjaden, 2016; Lam, Tjaden, & Wilding, 2012). It should be noted that the goal of big mouth is discussed loosely as targeting clear speech. Of the various instructions explored within the clear speech literature on Parkinson's disease, overenunciate (Lam & Tjaden, 2013, 2016; Lam et al., 2012) or enunciate (Levy, Moya-Gale, et al., 2016; Ramig et al., 2015) may most closely resemble this cue.

sentence and word levels. The greater durations and vocal intensity expected to result from these cueing strategies were further anticipated to correlate with greater intelligibility, especially in the older children and those with milder dysarthria (Boliek & Fox, 2014).

Method

This study received ethical approval from the Institutional Review Board at Teachers College, Columbia University.

Participants

Children With CP

Speech recordings were collected from eight children with spastic CP as diagnosed by a neurologist. They ranged in age from 4;8 to 14;3 (years;months). All were native speakers of American English although two participants (both English-dominant) spoke another language at home. Each child exhibited clinically notable dysarthria as determined by two certified speech-language pathologists. The speech-language pathologists determined the characteristics and severity of the dysarthria by consensus on the basis of the children's clinical evidence of motor speech impairment in one or more of the subsystems of speech (respiration, phonation, articulation, and resonance) that was observable audibly and/or visually (Fox & Boliek, 2012; Lee et al., 2014). Further inclusion criteria were as follows: (a) used speech as the primary mode of communication; (b) were able to follow simple commands, including repeating short phrases; and (c) passed a hearing screen at 20 dB HL (American National Standards Institute, 2004) for 500, 1000, 2000, and 4000 Hz bilaterally. Participant characteristics, including Gross Motor Function Classification System (Palisano et al., 1997) and receptive language skills, are provided in Table 1. Receptive language skills were measured by means of selected subtests from one of two standardized tests (i.e., the Test for Auditory Comprehension of Language–Third Edition, Carrow-Woolfolk, 1999, and the Clinical Evaluation of Language Fundamentals–Fifth Edition, Wiig, Semel, & Secord, 2013), depending on the child's age and visual and motor limitations. However, as also reported by Hustad et al. (2010), the adaptations suggested in the testing manuals did not always suffice for this population; thus, the scores are provided as gross measures of language comprehension but likely underestimate the children's skills.

Listeners

Fifty-one American English–speaking participants undertook the listening task; however, the final analysis was completed using data from 48 participants (13 men, 35 women, average age = 25 years, age range 18–35 years). Results from three listeners were excluded due to technical difficulties during data collection (two participants) and subsequent report of a preexisting traumatic brain injury (one participant). All participants were recruited from the New York City area and passed a pure-tone hearing screen at 25 dB HL (American National Standards Institute, 2004) for 500, 1000, 2000, and 4000 Hz bilaterally. Listeners reported no significant history of contact with persons with a motor speech disorder or history of language, learning, or cognitive disabilities. Listeners were rewarded for their participation by being entered into a raffle for gift cards.

Speech Stimulus Acquisition and Selection

Early Development of Big Mouth and Strong Voice Cues and Instructions

A clinical pilot study examining the use of clear speech and loud voice cues revealed that terminology changes were needed to make the cues child-friendly and easy to understand. For example, for four of the five children, the original cue to speak clearly was received negatively; the children reported that this is what they were told to do regularly, often in a scolding tone. Furthermore, the use of *loud* prompted vocal strain in some children. As a result, we trialed a number of cue modifications and ultimately selected the cues "speak with your big mouth" (targeting clear speech) and "speak with your strong voice" (targeting louder speech) for the present study.

Table 1. Participant characteristics of the children with cerebral palsy.

Child	Age	Sex	Diagnosis	GMFCS	Dysarthria severity	Language comprehension	Other languages
CP1	4;8	F	Spastic hemiplegia	I	Severe	91st–above average[a]	N/A
CP2	8;8	M	Spastic diplegia	II	Mild	37th–average[a]	N/A
CP3	10;4	M	Spastic triplegia	III	Moderate	37th–average[a]	N/A
CP4	10;7	M	Spastic hemiplegia	I	Moderate	95th–above average[b]	N/A
CP5	11;10	M	Spastic quadriplegia	IV	Mild-to-moderate	25th–below average[b]	N/A
CP6	12;4	F	Spastic quadriplegia	IV	Mild-to moderate	0.4th–poor[b]	N/A
CP7	12;9	M	Spastic diplegia	III	Severe	5th–poor[a]	Some Bengali
CP8	14;3	M	Spastic quadriplegia, epilepsy, VP shunt	V	Severe	0.4th–poor[b]	Some French and Spanish

Note. GMFCS = Gross Motor Function Classification System.

[a]Percentile rank obtained from the Test for Auditory Comprehension of Language–Third Edition, Elaborated Phrases & Sentences subtest.
[b]Percentile rank obtained from the Clinical Evaluation of Language Fundamentals–Fifth Edition, Word Classes subtest.

Speech Stimuli

Stimuli were recorded as part of a larger study investigating speech production in children with dysarthria associated with CP. Three phrases from the Test of Children's Speech (TOCS+; Hodge, Daniels, & Gotzke, 2009; henceforth, sentences) and 21 single words (henceforth, words) produced within a carrier phrase were extracted for use in the current experiments. The sentences *Find all the crayons, Three little pink pigs,* and *Don't splash any water* were selected as they sampled a range of vowels, consonants, and consonant clusters. The single word list represented confusable vowel and consonant pairs (e.g., *pat–pot, ship–sip*): *back, bad, bag, bat, chip, den, dot, jack, knot, mad, pack, pat, peek, pink, pot, sack, shack, sheep, ship, sip,* and *ten*. These single words were uttered in the carrier phrase "They say CVC(C) again." Phrase-level stimuli and words embedded in carrier phrases (henceforth, word level), rather than isolated words, were used in an attempt to more readily approximate the continuous speech characteristics of everyday communication.

Speech Recording Procedure

Each child attended a single recording session, conducted in a quiet room. To elicit the changes in speech production, instructions and a combination of visual and verbal cueing were provided as well as prerecorded examples from a model speaker. This process is described in further detail below and illustrated in online Supplemental Material S1 or at http://tinyurl.com/zhmleay.

For speech recording, a Countryman EMW Lavalier microphone was placed on the child's forehead and secured (with tape and a headband) 8 cm from the child's lips. Because vocal intensity was a variable of interest, a calibration procedure was completed to ensure that SPLs could be compared across children and conditions. Specifically, the experimenter noted the SPL on a sound level meter (Galaxy CheckMate CM140) that was placed 8 cm from a tuner (OT120-Korg Orchestral) producing a calibration tone. The speech signal was recorded using SoundForge 8.0 software on a Dell Optiplex 760 computer via a Scarlett 2i2 audio interface (Scarlett2i2, Focusrite 2x2 USB2). The input dial setting remained the same throughout the study. The children's speech was recorded at a sampling rate of 22050 Hz with 16-bit resolution on a mono channel.

For all children, the habitual condition was performed first. This was to negate any possible carryover effects of condition (McAuliffe, Kerr, Gibson, Anderson, & LaShell, 2014; Tjaden & Wilding, 2004). The habitual condition was followed by either the big mouth or strong voice conditions with the order of experimental conditions counterbalanced across the children. In completing the stimulus recording, the child sat in front of an experimenter. Before recording began, the child was provided with verbal instructions regarding the procedure and introduced to a mascot—the "Hawaiian Lion" puppet—who delivered cues and provided a visual reminder of the task instructions. In addition, children were shown further visual reminders: a drawing of a cartoon character with a large, open mouth. Furthermore, to facilitate the children's understanding of the task requirements and to ensure that a consistent model was provided, we prerecorded a model speaker producing the utterances in habitual, big mouth, and strong voice conditions.[2]

For the habitual condition, the children were simply asked to repeat what the speaker said. For each utterance, they were shown a picture of the target on a laptop computer screen. At the same time, they heard the required utterance as spoken by the model speaker delivered by loudspeakers (Altec Lansing ADA 215) placed at a consistent distance from the child. For example, if the word was *ship* in the habitual condition, the child was shown a picture of a ship and heard the model speaker produce the word *ship* in her everyday speaking voice. They were then asked to repeat the utterance. Before the big mouth or strong voice condition, the experimenter instructed the children to "speak with your big mouth" or "speak with your strong voice," respectively, and provided feedback on their productions. Cues were often delivered by the "Hawaiian Lion" puppet and visual reminders from the cartoon character drawings were provided (as seen in online Supplemental Material S1). Again, children were provided with a picture of the target on a laptop computer screen and simultaneously heard the requested utterance as spoken by the model speaker. This process was followed across the three conditions. If children did not repeat the utterance, they were given reminders. Any response that was perceived to be an attempt at repeating the utterance was accepted unless the production was incomplete, in which case the child was prompted to repeat the utterance. If extraneous noise occurred during the production or if the child did not respond or was off task, the child was prompted to repeat the stimulus. Additional encouragements or models were provided if the child exhibited fatigue or disinterest in the task. Breaks were provided as needed.

Regarding the model speaker's productions, these were recorded by a female adult speaker of American English from the New York City regional area. Details regarding the speaker's average duration and average SPL for words and sentences across the three conditions are provided in Table 2. To demonstrate the change in speech production elicited by these cues within the single model speaker, we undertook repeated-measures analyses of variance with Bonferroni-corrected post hoc pairwise comparisons. As can be seen in Table 2, the big mouth condition elicited significant increases in duration, approximately twice the length of the habitual condition across words and sentences (both ps < .05). This was coupled with minimal change ($p > .05$) to intensity in the sentence condition and a significant decrease in intensity in the single word condition

[2]Our clinical pilot work revealed that when children were cued visually and verbally only, they maintained the speech styles for the first few stimuli and subsequently reverted to their habitual speech. Hence, a repetition/imitation paradigm was used for this study. Prior studies have noted that these tasks can provide valid and informative data regarding intelligibility and rate of speech in children with dysarthria (e.g., Hodge & Gotzke, 2014; Hustad, Schueler, Schultz, & DuHadway, 2012).

Table 2. Acoustic results at sentence and word levels for adult model speaker across speech conditions.

Level	Habitual, *M* ± *SD*	Big mouth, *M* ± *SD*	Strong voice, *M* ± *SD*	$F(2, x)^a$	μ_p^2	Paired comparison, direction of effect
Sentences						
Duration (s)	1.33 ± 0.20	3.05 ± 0.10	1.71 ± 0.07	75.21	.993	BM > Hab* BM > SV* SV > Hab (*ns*)
Average SPL (dB)	59.94 ± 3.80	59.36 ± 2.91	62.81 ± 3.04	115.72	.996	SV > Hab (*ns*) SV > BM* Hab > BM (*ns*)
Words						
Duration (s)	0.31 ± 0.04	0.60 ± 0.12	0.32 ± 0.05	120.37*	.927	BM > Hab** BM > SV** SV > Hab (*ns*)
Average SPL (dB)	64.81 ± 4.35	62.13 ± 3.13	67.7 ± 4.41	51.91*	.845	SV > Hab** SV > BM** Hab > BM**

Note. SPL = sound pressure level; Hab = habitual; BM = big mouth; SV = strong voice; *ns* = not significant.
[a]$F(2, 1)$ for sentences; $F(2, 19)$ for words.
*$p < .05$. **$p < .001$.

($p < .001$). In contrast, the strong voice condition resulted in significantly increased intensity ($p < .001$) at the word level paired with minimal changes to duration relative to those invoked by the habitual condition ($p > .05$). At the sentence level, the strong voice condition resulted in minimal increases in intensity coupled with minimal increases in duration (both *p*s > .05).

Listening Tasks

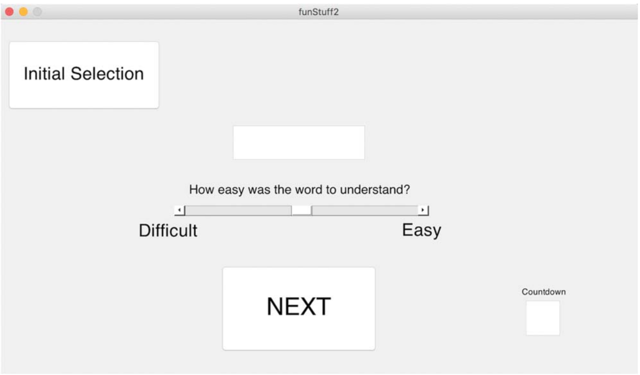
Each of the 48 listeners completed two listening tasks in a single lab visit of approximately 45 min. Both experiments were undertaken using custom-developed software (Chang & Chang, 2015) programmed in MATLAB (Version R2015b, The MathWorks, Inc., 2015) and presented on a laptop computer. The experiment was conducted free-field in a sound-attenuated booth. To ensure that speech stimuli were presented to listeners at a level representative of the children's speaking amplitude, the calibration tone's SPL measured prior to the recording of the children's productions (see "Speech Recording Procedure" section) was reproduced at 8 cm from the loudspeakers, thus replicating the recording conditions. Listeners were encouraged to sit in a comfortable position to access the computer and not to lean in toward the stereo loudspeakers (Altec Lansing ADA 215), which were connected directly to a MacBook Air computer (Model A1466). Listeners sat 85 cm from the loudspeakers, a typical distance between conversational interlocutors in the United States (Hall, 1966). Both tasks were preceded by a short familiarization experience in which listeners completed the same task with similar stimuli recorded by a child without dysarthria. Familiarization stimuli included six single words for Listening Task 1 (words that were not included in the stimulus list) and six TOCS+ sentences for Listening Task 2 (again, these sentences were not included in the experimental task). Listening Task 1 was always completed first to ensure that orthographic transcriptions were not influenced by familiarity with the speaker's speech from a previous task (Borrie, McAuliffe, & Liss, 2012).

Listening Task 1: Single Word Transcription and Ease-of-Understanding Rating

In the single word transcription and rating task, each listener heard 21 (different) single words (seven from each of the three conditions) spoken by a single child only. Listeners were assigned to a child randomly so that the final transcription data file included two transcriptions of each word spoken by each child in each condition. This was deliberate to ensure that it was representative of everyday listening (i.e., listeners commonly speak to one child at a time) and to optimize assessment of any within-speaker differences as a function of speech modification. Moreover, listening to only one child provided consistency for listeners throughout the task, given the known effects of multiple speakers on perceptual processing (e.g., Mullennix, Pisoni, & Martin, 1989).

After hearing a word in the carrier phrase, listeners were asked to complete two tasks: (a) type exactly the word they thought the child had said and (b) rate how easy the word was to understand on a visual analogue scale (VAS) with the anchor points *difficult* to *easy*. Although this resulted in rating scores that were not independent from the PWC, it permitted listeners to hear each word only once rather than a second time to avoid learning effects (Wilson, Bell, & Koslowski, 2003). Figure 1 provides a screenshot of the single word listening program. Each word was presented in the carrier phrase "They say (WORD) again." Task instructions were provided verbally and in written form prior to beginning. In brief, listeners were informed that some of the children might be difficult to understand but that all words were real English words. Furthermore, they were instructed to listen carefully as sound files would be played once only.

Figure 1. A screenshot of the Word Transcription VAS custom-developed software (Chang & Chang, 2015).



Listening Task 2: Sentence Ease-of-Understanding Rating

In the next task, sentence intelligibility judgment, listeners were instructed that they would hear children saying a series of phrases. After the presentation of each phrase, listeners were asked to judge how easy the sentence was to understand on a VAS with the anchor points *difficult* to *easy*. Each listener heard a total of 72 phrases (three sentences × eight children × three conditions) with a further eight stimuli played for reliability analysis. In this task, each listener heard the three target sentences spoken by each of the eight children across all three conditions. The task focused on global ease of understanding (not intelligibility as measured by orthographic transcription) across conditions; hence, it was preferable for each listener to hear each stimulus item across the three conditions. However, in order to minimize effects of multiple speakers (e.g., Mullennix et al., 1989) and to optimize listener responses to within-speaker changes across the three speech conditions, stimuli were presented blocked by speaker with phrases of the individual children presented randomly within the speaker block. Speaker blocks were randomized to minimize order effects.

Data Analysis

Acoustic and Perceptual Analyses

Four acoustic measures of interest were examined in the habitual, big mouth, and strong voice conditions: (a) duration, (b) SPL, (c) F1, and (d) F2. Duration and SPL were measured across utterances (for the TOCS+ sentence task) and words (for the word task). These two measures were used to verify the presence of production differences between the big mouth and strong voice conditions. Other adjustments may accompany these conditions, but adjustments in speech rate and vocal intensity were the most obvious changes expected (Smiljanić & Bradlow, 2009; Tjaden, Richards, et al., 2014; Uchanski, 2005). Each sentence and word was manually segmented (by research assistants and the second and third authors) at the sentence and word levels, respectively. Standard acoustic criteria were used to determine onset and offset (Klatt, 1975; Levy & Law, 2010). Duration (in seconds from onset to offset) and SPL of the sentences and words were extracted by custom Praat scripts (Boersma & Weenink, 2006). (Input level remained unchanged throughout the recording session; thus, vocal intensity was measured by measuring average SPL in each utterance.) These measures were obtained using a combination of a wideband spectrogram and the waveform in Praat. Note that the youngest participant, CP1, was excluded from spectral analyses because of poor reliability—likely due in part to her hypernasal vocal quality obscuring the formants.

In addition, F1 and F2 were obtained by means of the wideband spectrographic display as well as the linear predictive coding spectrum for a 25-ms window centered at the temporal midpoint of a subset of vowels /æ, ɑ/ for the words *pat* and *pot,* respectively. The intent of the spectral analysis was to investigate if greater mouth opening was achieved across either condition with the hypothesis that a higher F1 in either speech modification would be representative of a lower tongue position (likely resulting from a greater mouth opening), and a shift in F2 would indicate a change in the front–back dimension of the tongue (Stevens & House, 1955). Spectral changes have been found with clear speech with F1 increasing across vowels and higher F2 of clearly produced front vowels and lower for clearly produced low vowels (e.g., Ferguson & Kewley-Port, 2002). As Ansel and Kent (1992) found front–back vowel contrasts to be one of four parameters that account for a large degree of variance in intelligibility in adults with dysarthria due to CP, we examined changes in this subset of front and back vowels.

For perceptual analysis, two final sets of data were yielded: (a) sentence VAS ratings and (b) single-word VAS ratings and PWC scores. The PWC scores were calculated from the orthographic transcriptions, with words considered correct if they matched the target exactly or were homonyms or obvious misspellings of the target or homonym. For the rating task, mean intelligibility VAS ratings were calculated.

Reliability

To ensure the reliability of the acoustic findings, 20% of the original sentences and words were randomly selected and manually rechecked by a second judge (interrater reliability). Cronbach's α was used as a measure of agreement, with a value above .95 for interrater reliability for acoustic measures taken at the word level and a value above .96 for acoustic measures taken at the sentence level. For reliability of the F1 and F2 measurements, the vowels in the selected words *pat* and *pot* were manually checked by a second judge. Cronbach's α was again used as a measure of agreement between the raters, with a value above .98 for interrater reliability across all measures.

Statistical Analysis

To determine if significant differences in acoustic parameters (SPL, duration, F1, F2) existed across the three conditions (habitual, big mouth, strong voice), repeated-measures analyses of variance were conducted followed by post hoc pairwise comparisons with Bonferroni correction. Both linear mixed effects and binomial mixed effects analyses were conducted to assess intelligibility changes at the group level. For the data collected on the VAS scale (both sentences and words), we ran separate linear mixed effects models to examine the fixed effect of speaking condition and included random effects of listener and speaker. For the PWC data, we used binomial mixed effects modeling, again examining the fixed effect of speaking condition and including random effects of listener and speaker.

Results

Acoustic Changes Across Conditions

Sentences

Table 3 presents mean group acoustic data for duration and SPL across the three conditions (please see Appendix for individual data). As can be seen, there were significant effects of speaking condition for both duration, $F(2, 22) = 38.67$, $p < .001$, $\mu_p^2 = .78$, and SPL, $F(2, 22) = 16.41$, $p < .001$, $\mu_p^2 = .60$. Post hoc tests confirmed that duration was significantly higher in the big mouth condition compared with both the habitual and strong voice conditions ($p < .001$). Duration in the strong voice condition was also significantly greater than in habitual condition ($p = .006$). The SPL was significantly increased in the strong voice condition relative to the habitual ($p < .001$) and big mouth ($p = .001$) conditions, and SPL in the big mouth condition was significantly higher than in the habitual condition ($p = .004$).

Words

Table 4 demonstrates mean group data for duration, SPL, and F1/F2 across the three speaking conditions (please see Appendix for individual data). Statistical analysis revealed significant main effects of speaking condition for both duration, $F(2, 164) = 52.88$, $p < .001$, $\mu_p^2 = .39$, and SPL, $F(2, 164) = 122.09$, $p < .001$, $\mu_p^2 = .60$, respectively. Post hoc tests confirmed that word duration was significantly longer in the big mouth condition compared with both the habitual and strong voice conditions ($p < .001$). SPL was significantly higher in the strong voice condition relative to the habitual ($p < .001$) and big mouth ($p = .001$) conditions. In addition, SPL was significantly higher in the big mouth condition relative to habitual ($p < .001$).

As can be seen in Table 4, varying degrees and directions of change were observed in F1 and F2 for the vowels in two words, *pat* (/æ/) and *pot* (/ɑ/), across the three conditions. Repeated measures analysis of variance revealed no statistically significant changes in F1, $F(2, 5) = 0.47$, $p = .65$, $\mu_p^2 = .16$, and F2, $F(2, 5) = 0.22$, $p = .81$, $\mu_p^2 = .08$, for *pat* or in F1, $F(2, 5) = 2.08$, $p = .22$, $\mu_p^2 = .45$, and F2, $F(2, 5) = 6.51$, $p = .04$, $\mu_p^2 = .72$, for *pot* across the three conditions.

Changes in Intelligibility Across Conditions

Sentences

Figure 2 presents average ease of understanding ratings (and standard error) for each of the children with dysarthria across the three speaking conditions. The children's data are presented in order of severity of dysarthria (in the habitual condition) to permit visual examination of patterns of intelligibility change. Figure 2 indicates that prompting the children to use a big mouth or a strong voice resulted in positive changes to VAS ratings although the preferred condition and degree of change varied considerably across children. Linear mixed effects analysis revealed a significant increase in listeners' ease of understanding in both the big mouth ($\beta = 8.23$, $p < .001$) and strong voice conditions ($\beta = 7.29$, $p < .001$) relative to the habitual condition. There was no significant difference between the big mouth and strong voice conditions ($\beta = -0.94$, $p > .05$).

Words

Figure 3 presents the average ease of understanding ratings (and standard error) for each of the children with dysarthria across the three speaking conditions at word level. The findings appear similar to those from the sentence rating task in that both big mouth and strong voice had positive effects, in general, on listeners' ease of understanding. This was confirmed statistically; linear mixed effects analyses revealed a significant increase in listeners' ease of understanding in both the big mouth ($\beta = 11.38$, $p < .001$) and strong voice conditions ($\beta = 5.00$, $p < .01$) relative to the habitual condition. However, analysis also revealed that listeners' ease of understanding ratings were

Table 3. Acoustic results at the sentence level for children with cerebral palsy ($n = 8$) across speech conditions.

Parameter	Habitual, *M* ± *SD*	Big mouth, *M* ± *SD*	Strong voice, *M* ± *SD*	*F*(2, 22)	μ_p^2	Paired comparisons, direction of effect
Duration (s)	1.97 ± 0.62	3.05 ± 0.54	2.30 ± 0.45	38.67**	.78	BM > Hab** BM > SV** SV > Hab*
SPL (dB)	55.47 ± 4.66	58.64 ± 4.45	61.01 ± 4.39	16.41**	.60	SV > Hab** SV > BM* BM > Hab*

Note. SPL = sound pressure level; Hab = habitual; BM = big mouth; SV = strong voice.
*$p < .05$. **$p < .001$.

Table 4. Acoustic results at the word level for children with cerebral palsy (n = 8)[a] across speech conditions.

Parameter	Habitual, *M* ± *SD*	Big mouth, *M* ± *SD*	Strong voice, *M* ± *SD*	$F(2, 164)$	μ_p^2	Paired comparisons,[b] direction of effect
Duration (s)	0.45 ± 0.16	0.59 ± 0.16	0.46 ± 0.13	52.88**	.39	BM > Hab**
						BM > SV**
						SV > Hab (*ns*)
SPL (dB)	51.33 ± 5.44	56.35 ± 5.92	58.33 ± 5.39	122.09**	.60	SV > Hab**
						SV > BM*
						BM > Hab**
First formant (F1)						
pat	907 ± 152	943 ± 195	920 ± 138	0.47	.16	
pot	825 ± 171	890 ± 108	865 ± 146	2.08	.45	
Second formant (F2)						
pat	1,919 ± 164	1,944 ± 245	1,903 ± 174	0.22	.08	
pot	1,466 ± 239	1,392 ± 178	1,570 ± 236	6.51*	.72	SV > BM*

Note. SPL = sound pressure level; Hab = habitual; BM = big mouth; SV = strong voice; *ns* = not significant.

[a]One participant (CP1) was excluded from the F1 and F2 analyses as her formants were deemed unreliable, likely due to her hypernasality.
[b]For F1 and F2, the pair with $p < .05$ is listed only under significant paired comparisons. The rest are statistically nonsignificant.
$^*p < .05$. $^{**}p < .001$.

significantly higher in the big mouth condition relative to the strong voice condition (β = 6.37, p = .001).

Word intelligibility was also examined through orthographic transcription and showed a similar pattern of results to that of the VAS ratings (see Figure 4). Binomial mixed effects modeling revealed a significant increase in listeners' PWC in both the big mouth (β = 0.85, $p < .001$) and strong voice conditions (β = 0.40, $p < .05$), relative to the habitual condition. Furthermore, and in line with the VAS rating results, listeners' PWC was significantly higher in the big mouth condition than in the strong voice condition (β = 0.45, $p < .05$).

Intelligibility Changes for Individual Speakers Across Conditions

Our analysis showed that, in both sentences and words, listeners exhibited statistically significant improvements in intelligibility ratings in both the big mouth and strong voice conditions relative to habitual speech for the

Figure 2. Average visual analogue scale (VAS) rating of sentences for the eight children with dysarthria across habitual, big mouth, and strong voice conditions. Children are listed in order of severity of dysarthria in habitual condition. Standard error bars are included.

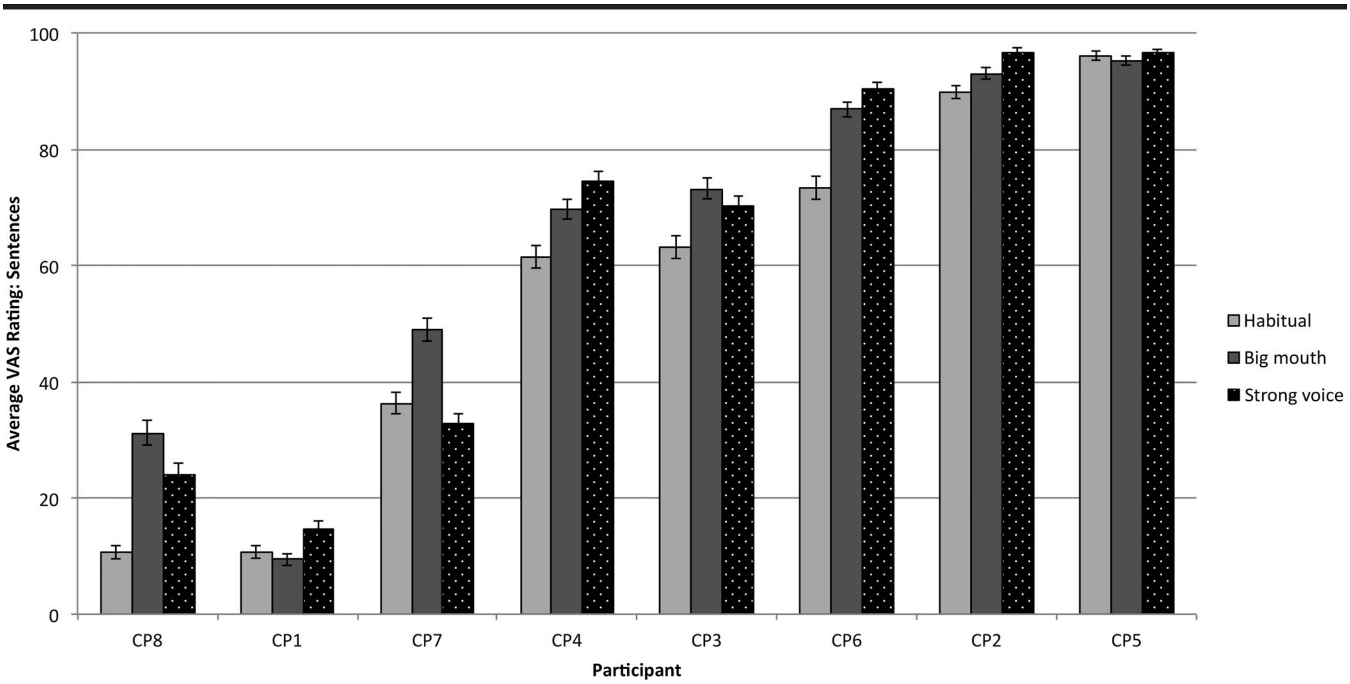
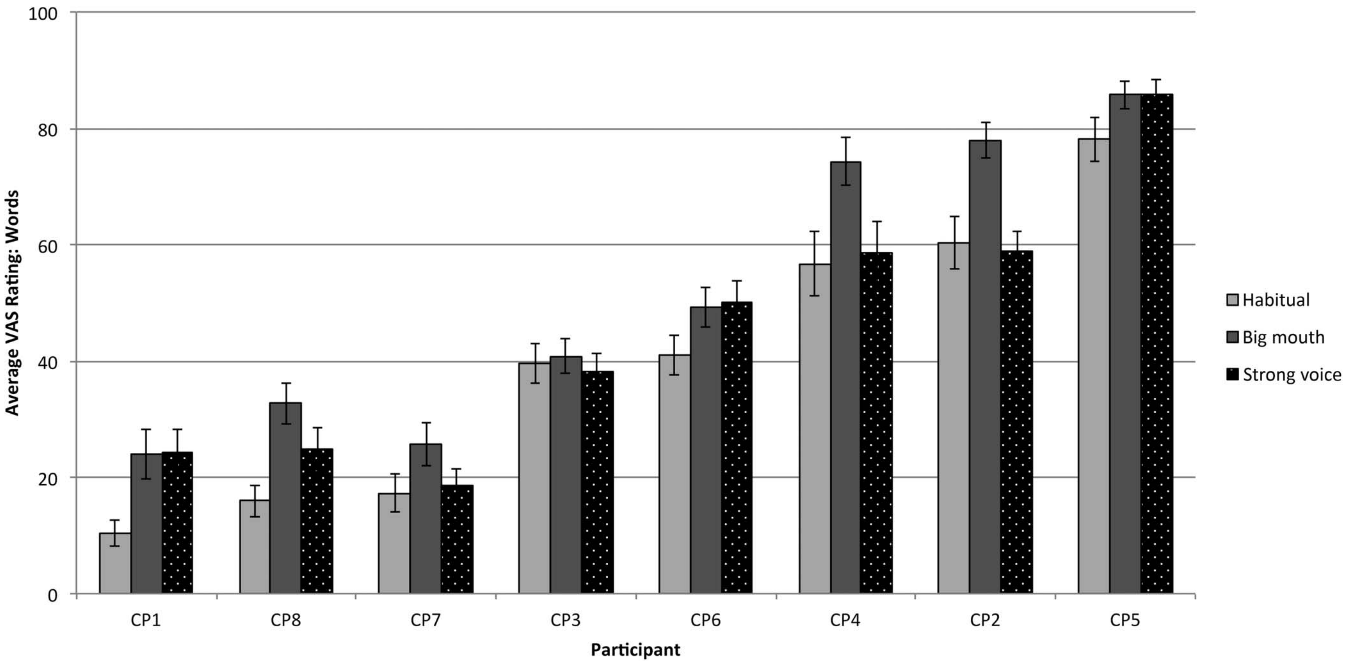
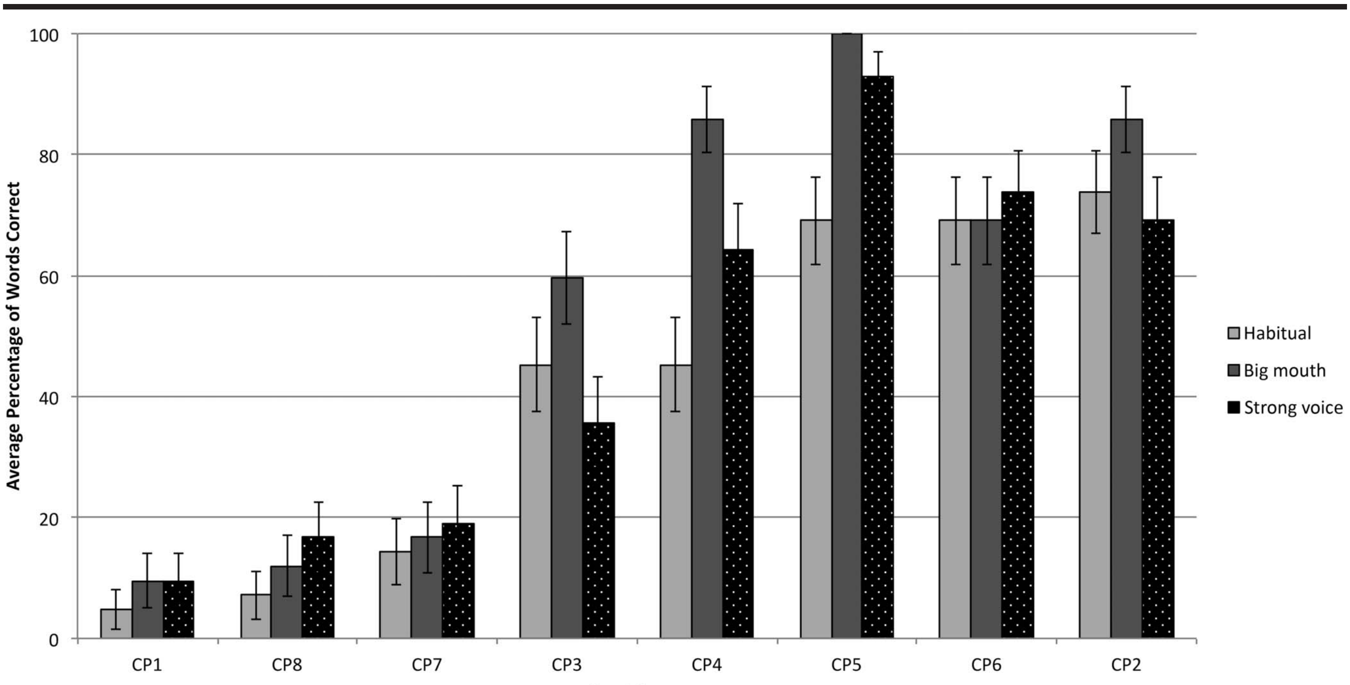


Figure 3. Average visual analogue scale (VAS) rating of words for the eight children with dysarthria across habitual, big mouth, and strong voice conditions. Children are listed in order of increasing VAS rating in habitual condition. Standard error bars are included.



group. In sentences, both conditions were similarly preferred (i.e., no significant difference between conditions); however, at the word level, the big mouth condition was preferred over the strong voice condition. As can be seen from Figures 2 through 4, there was considerable variation in children's overall scores and their responses to the behavioral modifications. Given this variation and the small number of participants, we undertook further descriptive

Figure 4. Average percentage of words correct (PWC) for the eight children with dysarthria across habitual, big mouth, and strong voice conditions. Children are listed in order of increasing PWC in habitual condition. Standard error bars are included.



analysis of individual children's performance across conditions relative to their baseline intelligibility to explore if listeners exhibited a strong preference for a particular condition with certain children or if age or severity of the child's dysarthria may have influenced the findings.

Examination of individual participant data presented in the figures indicated that, consistent with the group results, both the big mouth and strong voice conditions generally resulted in improved intelligibility scores/ratings for each child. Overall, no clear pattern could be ascertained regarding which cue effected the greatest change for particular children. Regarding the age of the children, the youngest child (CP1) and the oldest child (CP8)—both of whom exhibited the most severe dysarthrias of the group—experienced large increases in intelligibility following both cues. However, unlike the oldest child, the youngest child benefited at the word level far more than at the sentence level—perhaps because the length and complexity of the sentences may have been most difficult for her to reproduce. No patterns related to severity of dysarthria could be determined from visual inspection of the data.

Discussion

There has been limited study of interventions for speech disorders in children with dysarthria associated with CP (Pennington et al., 2009). Therefore, the current study aimed to determine if children with dysarthria were capable of producing objective changes in speech production following the child-friendly global cues of speaking with a big mouth and strong voice and, subsequently, if the cues would result in greater intelligibility at the sentence and word levels. First, acoustic analysis indicated that the children in this cohort were indeed capable of changing their speech production in response to cues to speak with a big mouth and strong voice. Second, the group exhibited significant increases in intelligibility at the sentence and word levels in response to both cues. Third, differential responses were observed at the word level, with the big mouth cue exhibiting significantly greater intelligibility improvements than the strong voice cue. Fourth, descriptive analysis revealed no obvious relationships between the children's age or dysarthria severity in their response to the different cues. The results are compared with findings from studies on related populations, and implications for treatment strategies are considered.

Acoustic Changes Across Conditions

At the outset, it was not evident that the children with the motor (and possibly motor learning) limitations inherent to CP would be capable of changing their speech, particularly in the big mouth condition. However, our acoustic measures indicated that the children with dysarthria in this cohort were capable of producing differential changes in their speech in response to the two treatment cues. To the authors' knowledge, this is the first study to examine this population's stimulability to behavioral speech modifications, but our findings generally agree with the literature on typically developing children and adults with dysarthria—that is, young, typically developing children are able to imitate slow and hyperarticulated speech produced by adults (Eaton & Ratner, 2013; Leone & Levy, 2015). In a similar manner, despite their diverse motor limitations, adults with dysarthria due to multiple sclerosis and Parkinson's disease (PD), among other neurological disorders, are capable of significant speech change in response to cues to speak slower, clearer, or louder (McAuliffe et al., 2014; McRae, Tjaden, & Schoonings, 2002; Tjaden, Richards, et al., 2014; Tjaden & Wilding, 2004).

When prompted to speak with a big mouth in response to an adult speech model, the children increased their sentence and word durations. In the big mouth condition, durations increased even more than in the strong voice condition, consistent with clear and loud speech studies on adults with PD (Tjaden, Richards, et al., 2014). Although spectral analysis of the subset of words with the vowels /æ/ and /ɑ/ did not reveal significant change from the habitual to the big mouth condition, all of the children produced the low back vowel /ɑ/ with a higher F1 in the big mouth condition than in their habitual speech, likely reflecting increased jaw displacement in this condition. The trend in F2 changes in this subset was consistent with findings from clear speech studies of the tongue being more fronted for front vowels (e.g., /æ/; Ferguson & Kewley-Port, 2007) than in habitual speech. Caution should be exerted, however, in the interpretation of the limited spectral data. The big mouth condition was associated with increases in intensity, similar to clear speech in adults with dysarthria due to PD and multiple sclerosis (Tjaden et al., 2013) even though, in the current study, the adult speaker model demonstrated a decrease in her intensity in this condition.

More is known about children's ability to manipulate their vocal intensity than about their ability to produce clear speech. As expected, the children with dysarthria produced speech with the greatest vocal intensity across all speech tasks when cued to speak with a strong voice. Longer durations accompanied the increased intensity. These findings were consistent with prior studies of children with CP that demonstrated increases in vocal intensity and longer durations following 4 weeks of treatment focusing on healthy loudness in children (Boliek & Fox, 2014; Levy et al., 2012). Rate reduction accompanying intensity increases has also been found in adults with dysarthria (e.g., Tjaden et al., 2013).

It is interesting to note that although the children modified their productions when cued, they did not consistently shadow (or succeed in shadowing) the adult model's speech style. For example, whereas the adult speaker did not increase her vocal intensity in the big mouth condition, the children did. Furthermore, although the adult speaker showed a nonsignificant increase in her vocal intensity in the strong voice relative to the habitual condition at the sentence level (but a significant increase at the word level), the children demonstrated a significant increase at both levels. It is, therefore, possible to conclude that when provided with these speech cues, the children modified their speech in a manner somewhat independent of the adult model's.

Although beyond the scope of the current investigation, it is likely that other acoustic changes, such as greater dynamic pitch range, spectral tilt, F0 range, F2 slope, fricative and affricate rise time, and noise duration (Ansel & Kent, 1992; Kim, Weismer, Kent, & Duffy, 2009; Neel, 2009; Smiljanić & Bradlow, 2009; Tjaden, Richards, et al., 2014; Tjaden & Wilding, 2004; Yunusova et al., 2012) may also have arisen in response to both speech cues. More detailed examination of acoustic changes in response to these cues is required—perhaps with a focus on articulatory and prosodic measures and their effects on intelligibility (DuHadway & Hustad, 2012; Lee et al., 2014; Patel & Campellone, 2009).

Changes in Intelligibility

In addition to the acoustic changes observed, both cues had significant positive effects on the ease with which the children's speech was understood. Converging evidence from the VAS ratings of the sentences, VAS ratings of the words, and PWC scores demonstrated that the children exhibited significant gains from both cues. Although the cues, population, and stimuli in the present investigation differed from those tested on previous clear speech studies, preventing direct comparisons to those studies, our results generally agree with studies on adults with dysarthria that have reported intelligibility increases for stimulated clear speech and/or loud speech (Beukelman, Fager, Ullman, Hanson, & Logemann, 2002; McAuliffe et al., 2014; Solomon, McKee, & Garcia-Barry, 2001; Tjaden, Richards, et al., 2014; Tjaden & Wilding, 2004). Increases of greater than 8% have been discussed as clinically meaningful (Stipancic, Tjaden, & Wilding, 2015; Tjaden, Sussman, & Wilding, 2014; Van Nuffelen, De Bodt, Vanderwegen, Van de Heyning, & Wuyts, 2010). Thus, both cues show promise as intervention strategies in children with dysarthria, increasing listeners' ease of understanding and ability to recognize words relative to the children's everyday speech production.

Both cues resulted in significant increases in ease of understanding across speech tasks at the word level, but differential responses were observed, with the big mouth cue yielding significantly greater improvements than strong voice. It appears possible that the cue to speak with a big mouth directly targets the articulatory subsystem deficits of children with CP. Although speculative, the acoustic changes may reflect productions of vowels that more closely approximate distinct canonical vowels as has been reported in clear speech studies (e.g., Ferguson & Kewley-Port, 2002, 2007; Leone & Levy, 2015; Tjaden et al., 2013), thereby helping the listener differentiate the words through potentially reducing the number of lexical competitors.

Although future studies are required to replicate this finding, our results are in line with those from adults with dysarthria that clear speech is consistently demonstrated to have a robust effect on spectral characteristics (Smiljanić & Bradlow, 2009; Tjaden, Kain, & Lam, 2014; Tjaden et al., 2013). Clinically, for the children with CP studied here, it appears that either cue may be of benefit. However, although the sentence-level task provided a global measure of ease of understanding and revealed improvements following both cues, the listeners were exposed to various speakers uttering the same sentences, potentially affecting their judgments. The word-level transcription task captured the children's intelligibility gains more objectively (Hustad, 2007) as the listeners were required to indicate the words they heard (as well as their ease of understanding) with no semantic or syntactic cues provided. Thus, in the absence of linguistic cues, a likely occurrence when a child's dysarthria is relatively severe, a big mouth cue may result in the greatest benefit. More studies are needed to determine the relationship between children's linguistic skills and intelligibility-enhancing cues.

Although the children benefited from both cues significantly overall, no clear pattern could be ascertained regarding which cue yielded consistent improvements to intelligibility for particular children. Descriptive analysis did not reveal any clear trends toward either severity of dysarthria or age being associated with an advantage in the use of a particular prompt. Although that was the case, perhaps most encouraging was that all children were shown to benefit from the cues. Clinically, it appears that treatment with either cue is likely to result in improvement to intelligibility in children with CP, but that stimulability to various cues and their effects on intelligibility differ across children. Although there was overlap in the benefits of the two cues for most children (i.e., more intense speech with longer duration), the reasons one child may benefit more from a particular cue requires further exploration.

Conclusion and Future Directions

In conclusion, there have been few studies exploring the effects of various speech cues on intelligibility in children with dysarthria. To our knowledge, this is the first to compare two forms of global speech cues in this population. Although participant numbers in the current study were small, in general, our findings are consistent with the literature in adults with hypokinetic dysarthria, whose intelligibility benefits from both loud and clear speech (Tjaden, Richards, et al., 2014). Despite the individual differences, our findings add to growing evidence that there may be some universal benefit to clearer, louder speech for increasing intelligibility. With the overall intelligibility enhancements yielded by the global cues big mouth and strong voice, but the variability in the children and linguistic levels benefited, perhaps implementing the two cues in tandem might benefit the most children with dysarthria until variables that predict the most positive gains using particular techniques are established.

However, this study had a number of limitations that must be considered in the interpretation of its findings. An important difference between speech modification studies (e.g., Tjaden, Richards, et al., 2014; Tjaden & Wilding, 2004) and treatment studies (e.g., Fox & Boliek, 2012; Levy, 2014; Levy et al., 2012; Pennington, Smallman, & Farrier, 2006; Pennington et al., 2010, 2013) is that in modification studies speakers are cued to speak in a particular style, and speech models may be provided and could affect the productions. The results of this study represent speech style modifications under optimal conditions with maximal modeling and cueing. In treatment studies, in contrast, speakers are expected to learn to apply the new techniques, and cues are gradually faded. The speakers are expected to recruit the strategies independently, representing generalization and long-term changes in response to treatment. Thus, a crucial next step for our research is to establish if the children can learn to maintain the new speech styles and intelligibility gains in their daily lives. Additional studies are needed to examine the effects of the cues and of treatment that includes such cues on greater numbers of children and across dysarthria types. Moreover, as the nature of instructions affects speakers' acoustic changes (Lam & Tjaden, 2016; Lam et al., 2012) and intelligibility gains (Lam & Tjaden, 2013), further exploration of which particular instructions and cues may maximize intelligibility in children with dysarthria would help optimize treatment programs.

Acknowledgments

Thank you to the participants, their families, as well as to Ernest Chang, Renée Deschenes, Sarah Eldib, Robert Fromont, Andrew Gordon, Bethany Hetrick, Hsing-Ching Kuo, Sarya Majdalani, and Bhavini Surana.

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Appendix

Individual Acoustic Results (Mean Duration and Mean Sound Pressure Level [SPL]) at the Sentence and Word Level for the Children With Dysarthria Across Speech Style Conditions

Participants	Acoustic measures	Habitual	Big mouth	Strong voice
Sentences				
CP1	Mean duration	1.781	2.882	1.993
	Mean SPL	54.828	57.396	58.025
CP2	Mean duration	1.514	2.727	1.907
	Mean SPL	58.993	55.746	57.683
CP3	Mean duration	2.406	3.990	2.615
	Mean SPL	64.196	67.768	70.070
CP4	Mean duration	1.734	3.208	2.159
	Mean SPL	52.968	55.127	59.874
CP5	Mean duration	1.434	2.741	2.047
	Mean SPL	54.194	58.188	58.593
CP6	Mean duration	1.691	3.163	2.644
	Mean SPL	50.047	57.798	61.586
CP7	Mean duration	1.899	2.426	1.846
	Mean SPL	53.987	55.929	59.879
CP8	Mean duration	3.294	3.196	3.083
	Mean SPL	54.513	61.246	63.290
Words				
CP1	Mean duration	0.539	0.502	0.501
	Mean SPL	49.224	58.190	60.000
CP2	Mean duration	0.294	0.494	0.341
	Mean SPL	49.580	58.410	58.965
CP3	Mean duration	0.574	0.737	0.436
	Mean SPL	60.594	61.176	64.782
CP4	Mean duration	0.343	0.647	0.357
	Mean SPL	53.721	53.685	60.513
CP5	Mean duration	0.328	0.493	0.378
	Mean SPL	51.495	54.407	54.428
CP6	Mean duration	0.384	0.552	0.504
	Mean SPL	44.656	46.123	52.266
CP7	Mean duration	0.491	0.599	0.498
	Mean SPL	54.388	57.953	58.532
CP8	Mean duration	0.663	0.683	0.645
	Mean SPL	47.401	60.828	57.315