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Vowel Intelligibility in Children With and Without Dysarthria: An Exploratory Study

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Abstract

Children with dysarthria due to cerebral palsy (CP) present with decreased vowel space area and reduced word intelligibility. Although a robust relationship exists between vowel space and word intelligibility, little is known about the intelligibility of vowels in this population. This exploratory study investigated the intelligibility of American-English vowels produced by children with dysarthria and typically-developing children (TD). Three CP and five TD repeated words with contrastive vowels /i-ɪ/,/æ-ɛ/,/ɑ-ʌ/,/o-u/ produced by a native American-English adult. Adult listeners transcribed the utterances orthographically and rated their ease of understanding. Overall, CP presented with less-intelligible vowels than TD. For CP, a trend was found with the lowest intelligibility for /ɑ/ (CP=7%,TD=66%), /ɪ/ (CP=30%,TD=82%), and /ʌ/ (CP=38%,TD=99%), and more heterogeneous vowel confusions; however, intelligibility differences between vowels did not reach statistical significance. Clinical implications include that, unless further studies show vowel-specific effects, treatment targeting the entire vowel system may be warranted for increasing intelligibility.

Introduction

Fundamental to any speech communication is intelligibility, defined here as how accurately a talker's intended message (transmitted through the speech signal) is recovered by a listener (Kent, Weismer, Kent, & Rosenbek, 1989). A large population at risk for intelligibility deficits are children with cerebral palsy (CP). CP occurs in 1 of every 323 children in the United States (Centers for Disease Control and Prevention, 2014). Some estimate that 31% to 88% of individuals with CP present with the motor speech disorder of dysarthria (Havstam, Buchholz, & Hartelius, 2003). Children with dysarthria due to CP (henceforth "children with dysarthria") typically present with monotone, monopitch, strained voice quality, imprecise consonant and vowel production, and reduced vowel space area (Byrne, 1959; Fox & Boliek, 2012; Higgins & Hodge, 2002; Lee & Hustad, 2013; Levy, 2014; Levy, Ramig, & Camarata, 2012). In this population, the articulatory subsystem has been identified as a primary contributor to intelligibility (Lee, Hustad, & Weismer, 2014). The segmental and suprasegmental characteristics of vowels in children with dysarthria are underexplored and vowel performance is underreported (Kent & Rosenbek, 1983). Although vowel *accuracy* in children with dysarthria has been explored in a handful of studies, their vowel *intelligibility* remains poorly understood.

A robust relationship exists between reduced vowel space area in children with dysarthria and their reduced word intelligibility (DuHadway & Hustad, 2012; Higgins & Hodge, 2002; Lee & Hustad, 2013). DuHadway and Hustad found that in 30-36 month-old children with CP, of all acoustic variables measured (including vowel space area, articulation rate, and maximum utterance length), vowel space area was the strongest, and the only statistically significant and independent, contributor to word intelligibility. Similarly, in adults with dysarthria due to CP the degree of spectral overlap among vowels accounted for the greatest variance in word intelligibility scores—greater than F1 and F2 variability, vowel space, and distance between vowels (Kim, Hasegawa-Johnson, & Perlman, 2011).

Speech sound accuracy is typically determined by means of a researcher's or phonetician's narrow phonetic transcription of productions of known targets or semantic categories (e.g., Byrne, 1959; Platt, Andrews, & Howie, 1980; Platt, Andrews, Young, & Quinn, 1980). Vowels that are distorted (e.g., inappropriately nasalized or rounded) are typically tallied as inaccurate (Platt, Andrews, Young, & Quinn, 1980). In the few reports on *vowel accuracy i*n children with dysarthria, children with CP with spasticity, and especially those with athetosis, produced vowels less accurately than typically-developing children (Byrne, 1959). In Byrne's toy-naming task, although most vowels were produced by children with dysarthria with between 85% and 95% accuracy, the front vowels /i/ and /ɛ/ were found to be produced with the lowest accuracy. The low vowel /ɑ/ was produced with high accuracy (95%). Byrne suggests that the children's difficulty with tongue tip movement is responsible for this pattern. In Australian-English speaking adults with CP, Platt, Andrews, Young, and Quinn (1980) found the lowest accuracy for the vowels /i/, /æ/, and /ɑ/, consistent with Byrne's finding of decreased accuracy for the high front vowel, but not consistent with her finding of low vowel accuracy. The authors attribute difficulty producing corner vowels (by adults with dysarthria) to an inability to achieve the vocal-tract shapes required for the extreme vowel positions in the vowel quadrilateral.

While accuracy and intelligibility are related, a talker who distorts speech sounds in a consistent manner or to an extent that it does not change the identity of the speech sound can be easily intelligible (Peterson & Marquardt, 1981). The distinction between accuracy and intelligibility has important speech treatment implications. For individuals with speech sound disorders, treatment protocols prioritize intelligibility goals. Once intelligibility is established, accuracy and naturalness can be targeted (Yorkston, Beukelman, Strand, & Hakel, 2010).

Results from word intelligibility tasks yield important information about severity of intelligibility and the consistent relationship between acoustic vowel space and word intelligibility over time within talkers (Hustad, 2012; Lee & Hustad, 2013). Such findings, however, do not necessarily provide sufficient information for developing speech treatment approaches. Nickerson and Stevens (1980) emphasize that knowing what makes an utterance unintelligible helps determine how its intelligibility can be improved. To this end, Ansel (1985), Ansel and Kent (1992), and Kent et al. (1989) have applied a phonetic analysis approach using minimally contrasting pairs (henceforth, “minimal pairs”), identifying the aspects of speech that account for impairments in intelligibility in adults with dysarthria. Beyond typical word intelligibility tasks, this approach seeks to minimize contextual information that the listener relies upon for recovering the speech signal. Thus, the intelligibility of particular speech sounds (i.e., phonetic intelligibility) may be examined.

Using a minimal pair approach, Ansel and Kent (1992) found that high-low vowel contrast production difficulties contributed to word intelligibility deficits in adults with dysarthria due to mixed CP. Similarly, Ansel’s (1985) correlational study found that intelligibility was predicted in 16 adults with CP with 63% of the variance accounted for by the following acoustic-phonetic variables: affricate-fricative contrasts (e.g., chip-ship), back-front vowel contrasts (e.g., hot-hat), low-high vowel contrasts (e.g., hat-heat), and lax-tense vowel contrasts (e.g., heat-hit). Ansel and Kent posit that the vowel intelligibility deficits point to difficulty achieving tongue shapes, particularly for extreme vowels, consistent with accuracy studies by Platt, Andrews, and Howie (1980) and Platt, Andrews, Young, and Quinn (1980).

Although some preliminary work has been performed on phonetic intelligibility of children with speech sound disorders of unknown origin (Chung, Nearey, Hodge, Pollock, & Tucker, 2012; Hodge & Gotzke, 2011), using specially-designed software that elicits minimal pairs appropriate for young children (TOCS; Hodge & Gotzke, 2007), vowel intelligibility in children with dysarthria has not been explored. The present study used a minimal pair approach to investigate the intelligibility of American English (AE) vowels within words produced by children with dysarthria and TD. The contrasts “meat-mitt” (/i-ɪ/), “pan-pen” (/æ-ɛ/), “knot-nut” (/ɑ-ʌ/), and “soap-soup” (/o-u/) were selected based on Ansel and Kent’s (1992) finding of deficits in high-low vowel contrasts in adults with dysarthria due to mixed CP.

In the present exploratory study, intelligibility was determined by means of adult listening tasks involving children’s vowels in minimal-pair words. The listening tasks included orthographic transcriptions, considered the gold standard for intelligibility measurement (Hustad, 2006), as well as ratings of ease of understanding in order to capture adult listeners’ perceptions of the children’s intelligibility (Levy et al., 2012; Workinger & Kent, 1991).

It was hypothesized that children with dysarthria would produce vowels less intelligibly than would TD. Which vowels might be least intelligible was not evident. Peripheral vowels produced by the children with dysarthria might be expected to be confused with more central vowels because of the vowel space reduction in this population (Higgins & Hodge, 2002; Lee & Hustad, 2013) and previous accuracy studies (Byrne, 1959; Platt, Andrews, & Howie, 1980). Difficulty producing low back vowels would be in line with Higgins and Hodge’s (2002) deviant F1 values found for /ɑ/ produced by children with dysarthria and Platt, Andrews, and Howie’s (1980) accuracy findings with adult dysarthria; however, such difficulty would not be consistent with Byrne’s (1959) finding of high accuracy in /ɑ/ production by children with dysarthria.

An alternative prediction was that all of the children’s vowels would be similarly affected by their dysarthria, i.e., that no special difficulty would be found for particular vowels. This prediction would be supported by Tjaden, Rivera, Wilding, and Turner's (2005) finding that lax (typically more central) vowel space was also reduced in adults with predominantly spastic or spastic-flaccid dysarthria due to amyotrophic lateral sclerosis (ALS).

Methods

Participants

Three AE-speaking children (all female) with dysarthria participated as talkers in the study and were recruited through the Center for Cerebral Palsy at Teachers College, Columbia University. All had a diagnosis of spastic CP by a neurologist, a diagnosis of spastic dysarthria by two speech-language pathologists (SLPs), and parental reports that their speech was difficult to understand. Further inclusion criteria were the ability to follow basic directions and the use of speech as their primary form of communication. All were tested with a battery of speech sound, language, and cognitive assessments (e.g., the Test of Auditory Comprehension of Language-3 [TACL-3; Carrow-Woolfolk, 1998], the Kaufman Speech Praxis Test for Children [Kaufman, 1995], the Kaufman Brief Intelligence Test-2 [KBIT-2; Kaufman & Kaufman, 2004], the Arizona Articulation Proficiency Scale-3 [Arizona-3; Fudala, 2001]), as well as with informal speech and language evaluations. Talker characteristics of the children with CP are listed in Table 1. The children's level of gross motor function according to the Gross Motor Function Classification System (GMFCS; Palisano et al., 1997) is also listed. (The GMFCS is a five-level clinical scale used to classify gross motor function for children with CP, with Level I representing the fewest gross motor limitations.) The children's oral mechanism examinations were consistent with spastic dysarthria. The SLPs noted the children's decreased range of motion and labial and lingual weakness. The children's speech was described generally as slow and effortful, with a strained vocal quality, and monopitch and monoloudness. Intermittent hypo- and hypernasality and imprecise consonant and vowel articulation were also noted.

Table 1
Talker characteristics of children with dysarthria due to cerebral palsy (CP)

Participant	Gender	Age	Gross Motor Function Classification System (Palisano et al., 1997)	Dysarthria type	Dysarthria severity	Receptive language skills	Expressive language skills	MLU	Other diagnoses
CP1	F	3;3	II	Spastic	Moderate	Age-appropriate	Age-appropriate	3.7	Delayed phonological acquisition
CP2	F	8;10	I	Spastic	Mild	Age-appropriate	Delayed	3.2	-
CP3	F	9;7	II	Spastic	Moderate	Delayed	Delayed	1.8	Moderate apraxia

Five typically-developing children (TD) with no language, phonological or cognitive delays also participated as talkers in the study: TD1 (2;7 year-old girl), TD2 (3;9 year-old boy), TD3 (5;10 year-old boy), TD4 (8;3 year-old girl), and TD5 (9;2 year old girl). It was not possible to match for language age because, for example, a TD with a Mean Length of Utterance (MLU) of 1.8 (the MLU of CP3, who was 9;7 years old) would likely not comply with testing. Thus, instead, TD included a child of 2;7 years (approximately the youngest age feasible for testing and therefore the MLU closest to that of CP3) and 9;2 year old child (close to CP3's chronological age). Including more TD than children with CP rendered the two groups uneven, but provided a larger range for comparison of chronological and language age. All were born and raised in or near New York City.

Twenty-six adult listeners who were native speakers of AE, ages 21-46, were assigned to one of two groups. The listeners were first-year students in the master's program of Communication Sciences and Disorders at Teachers College, Columbia University. Exclusion criteria included significant (i.e., more than a few weeks of) experience working with children or adults with speech sound disorders. They were recruited via the internet following Institutional Review Board (IRB) approval. The first group listened to stimuli produced by the children with dysarthria. The second group listened to stimuli produced by the typically-developing children. Both groups received the same instructions (described below). Different groups of adult listeners were used for the two groups of children because few normative data exist on vowel intelligibility in TC and fewer still on vowel intelligibility in children with dysarthria. Thus, in the group listening to stimuli produced by TD, the listeners' perceptions of typical speech would not be influenced by hearing dysarthric speech with the same target vowels (and vice versa for the group listening to dysarthric speech), and learning of the stimulus items was reduced. However, this normative data collection strategy limited comparisons of transcription and judgment data across the groups of children. All children and adult listeners passed a bilateral hearing screening at 500, 1000, 2000, and 4000 Hz (American National Standard Institute, 2010) at 20 dB HL.

Stimulus materials and procedures

Data collection procedures were approved by the IRB at Teachers College, Columbia University. The children were recorded in a sound-attenuated booth at Teachers College. They were seated with no instructions regarding seating or posture, and a Shure headset microphone was placed 8 cm from the children's lips. The children were instructed to say what they heard. (Repetition tasks are often used with children to avoid confounds regarding naming, reading, and phonological target differences [Hodge & Gotzke, 2014; Leone & Levy, 2015].) No specific instructions (e.g., on effort, clarity or loudness) were given. The children repeated 3 recordings of words (i.e., 3 repetitions) with contrastive vowels ("meat-mitt" [/i-ɪ/], "pan-pen" [/æ-ɛ/], "knot-nut" [/ɑ-ʌ/], "soap-soup" [/o-u/]) produced by an adult native talker of AE in the same randomized order. Prior to the repetition task, the children were asked to name the objects in photos to determine their familiarity with the words. All were able to label the objects. For stimulus verification, three adult native talkers of AE transcribed the adult recordings orthographically. Transcription intelligibility of the adult recordings was 100%.

The signal passed through a mixer (Shure Prologue 200M) to the sound card (Turtle Beach Riviera) of a desktop computer (Dell Pentium 4). SoundForge 8.0 (Sony) software was used for recording with 16-bit resolution on a mono channel. Calibration involved a tone played by a KORG LCA-120 chromatic tuner adjacent to microphone. The experimenter noted (visually) the sound pressure level (SPL) of the tone on a Galaxy SP-meter 30 cm from the microphone. This was repeated at the end of sessions for later correction of the SPL of the audio recordings, as yielded by Praat (Boersma & Weenink, 2005).

Adult listening task

In preparation for the adult listening task, the stimuli were segmented and randomized for presentation. Praat (Boersma & Weenink, 2005) software was used to analyze the dB SPL value and to restore it to its original SPL value as indicated on the Galaxy SP meter during calibration (see Fox & Boliek, 2012). For the group listening to stimuli by children with dysarthria, one production of 8 words by each of the three children was presented. For the TD, listeners were presented with two productions of 8 words by each of the five children. Fewer stimuli were presented from children with CP because, although at least three stimuli per child were recorded, several stimuli were discarded due to noise created by the children's movements and intermittently explosive signals (Kent, Miolo, & Bloedel, 1994). The first stimulus without noise was used. Stimulus presentation was from a Dell Pentium 4 computer through Sennheiser HD 280 Pro headphones at a comfortable listening level, which was not changed throughout the study. For each stimulus presented, listeners transcribed the word orthographically and rated it on "ease of understanding." In the orthographic transcription task, listeners were instructed to write down the words they heard. In the rating task, listeners were asked to rate their ease of understanding the word using a 9-point Likert scale (1 = Very difficult to understand and 9 = Very easy to understand). Listeners typed their responses on an Excel spreadsheet on a laptop. They were permitted to listen to each word only once, except if they had not been attending, in which case they could request a replay. (Most listeners did not request replays. On the rare occasion that a listener requested a replay, no pattern was evident of any particular vowel or participant group's stimuli eliciting more replay requests than others.) Prior to the experimental task, a familiarization task was conducted in which recordings of words not in the study were presented to listeners for practice.

Two native AE speaking research assistants scored vowels (only) in listeners' transcriptions as intelligible or not intelligible based on whether the transcription was correct (i.e., whether it represented the target vowel of the word presented to the child for repetition). Vowels in homophones were scored as intelligible, as were orthographic transcriptions indicating unintelligible consonants but intelligible vowels. Inter-rater reliability (between the two raters) was 77% and intra-rater reliability (of responses to the same stimuli played twice for each rater) was 91%. Ratings of ease of understanding were obtained and the median score was calculated.

Results

Transcription intelligibility

Table 2 reveals transcription intelligibility (i.e., percent accuracy of the child's production of the target, as perceived by adult listeners) of each vowel produced by the children with dysarthria (1 utterance per vowel) and the typically-developing children (2 utterances per vowel), with participants listed in the first column and target vowel in the top row. Vowel intelligibility was lower in children with dysarthria (median = 50%, range = 0 - 100%) than TD (median = 97%, range = 22 - 100%). Medians and non-parametric statistics were employed due to the small sample size. A Mann-Whitney test was used to test for a difference in transcription intelligibility between children with dysarthria TD. Transcription intelligibility for children with dysarthria (median = 50) was significantly lower than for TD (median = 97%, $U = 251.0$, $p <$

.01, $r = -0.41$), as expected. In TD, in contrast, vowels produced by older children showed a trend of being overall more intelligible than those produced by younger children, although /æ/ remained problematic for the older children.

Table 2
Transcription intelligibility (i.e., percent accuracy of adult listeners' transcription) of children with dysarthria due to cerebral palsy (CP) and typically-developing children (TD)

Participant	Age	/i/ meat	/ɪ/ mitt	/æ/ pan	/ɛ/ pen	/ɑ/ knot	/ʌ/nut	/o/ soap	/u/ soup
CP1	3;3	100	0	100	100	0	60	70	10
CP2	8;10	20	0	40	90	0	40	100	70
CP3	9;7	100	90	60	20	20	10	30	70
Median		100	0	60	90	0	40	70	70
TD1	2;7	100	22	81	53	31	100	91	97
TD2	3;9	69	94	97	97	41	97	94	100
TD3	5;10	63	100	100	94	66	100	97	100
TD4	8;3	100	100	63	100	94	100	100	100
TD5	9;2	88	94	50	100	100	100	97	100
Median		88	94	81	97	66	100	97	100

Descriptively, for productions by children with dysarthria, /ɑ/ and /ɪ/ were least intelligible, whereas /i/ was most intelligible. Front vowels (/i-ɪ-ɛ-æ/) were more intelligible (median = 75% intelligibility) than central and back vowels (/o-u-ʌ-ɑ/; median = 35% intelligibility). Low vowels (/æ-ɑ/) were generally less intelligible (median = 30% intelligibility) than high (/i-ɪ-u/; median = 70% intelligibility) and mid vowels (/ɛ-ʌ-o/; median = 60% intelligibility). Peripheral vowels /i-ɑ-o-u/ (median = 50% intelligibility) were as intelligible as more central vowels /ɪ-ɛ-æ-ʌ/ (median = 50% intelligibility). A Kruskal Wallis test was performed to check for a significant difference in transcription intelligibility based on the target vowel. Transcription intelligibility was not significantly different as a function of target vowel in this small, heterogeneous sample of children with dysarthria, $H(7) = 7.07$, $p = 0.42$ or in TD, $H(7) = 12.81$, $p = 0.07$.

Transcription: vowel confusions

Table 3 is a confusion matrix that represents the listeners' responses to the stimuli as percentages of the total number of presentations for each target vowel produced by children with dysarthria and typically-developing children. The stimuli presented are listed in the left-hand column and the possible vowel responses are listed in the top row. The responses in boldface represent the percentage of accurately produced vowels, that is, those perceived as the target vowels, whereas the regular typeface represents errors. The greater variability in error responses for children with CP is evident in the table. For children with dysarthria, when vowels were not produced intelligibly, they were confused with their paired vowel approximately equally often (median = 29%) as a vowel not within their pair (median = 27%); however, for typically-developing children, within-pair vowel confusion was more frequent (median = 7%) than outside-pair confusion (median = 1%).

Table 3
Vowel confusion matrix for children with dysarthria due to cerebral palsy (CP) and typically-developing children (TD): Percent confusions. Responses in boldface represent accurately-produced vowels. Regular typeface represents errors.

		Response									
Stimulus		/i/	/ɪ/	/æ/	/ɛ/	/ɑ/	/ʌ/	/o/	/u/	/ʊ/	/eɪ/
/i/	CP	**73**	27								
	TD	**84**	11				1			4	
/ɪ/	CP	33	**30**	10		3	20				3
	TD		**82**	6	3		9				
/æ/	CP			**68**	32						
	TD			**78**	21						
/ɛ/	CP	3	27		**70**						
	TD		1	10	**89**						
/ɑ/	CP		7	56		**7**	30				
	TD		1	1		**66**	31				
/ʌ/	CP		23		7	32	**38**				
	TD					1	**99**				
/o/	CP					10	13	**67**	10		
	TD							**96**	4		
/u/	CP					10	3	28	**56**	3	
	TD							1	**99**		

As predicted, for children with dysarthria and TD, confusions within vowel pairs were primarily unidirectional, with the more peripheral vowel being confused with the more central vowel more frequently (children with dysarthria median = 29%, range = 27 - 32%; TD median = 16%, range = 1 - 31%) than central vowels being confused with peripheral vowels (children with dysarthria median = 21%, range = 0 - 33%; TD median = 3%, range = 0 - 10%).

Ratings of ease of understanding

As shown in Table 4, despite different listeners for the two populations of children, the vowels by the children with dysarthria were rated as less easy to understand than those produced by typically-developing children. A Mann Whitney test confirmed that children with dysarthria (median = 4) were rated as significantly less easy to understand by adult listeners than were TD (median = 7), $U = 30941.50$, $p < 0.001$, $r = -0.46$. For children with dysarthria and TD, the youngest child was rated as the least easy to understand (CP1 = 3; TD1 = 5). In addition, the majority (75%) of both groups' vowels were rated along the total range of the scale (1 - 9), suggesting variability in vowel intelligibility in both groups. Of interest, higher transcription accuracy was not necessarily associated with higher ratings of ease of understanding. The vowels produced by CP1 revealed higher transcription intelligibility (median = 65%) than those produced by CP2 and CP3 (median = 40% and 45%, respectively), but lower ratings (median = 3) than CP2 and CP3 (median = 4).

Table 4
Median transcription intelligibility and rating of ease of understanding for children with dysarthria due to cerebral palsy (CP) and typically-developing children (TD). (1 = Very difficult to understand, 9 = Very easy to understand.)

Participant	Age	Median transcription intelligibility	Median rating of ease of understanding	Range
CP1	3;3	65%	3	1-9
CP2	8;10	40%	4	1-9
CP3	9;7	45%	4	1-9
TD1	2;7	60%	5	1-9
TD2	3;9	86%	7	1-9
TD3	5;10	90%	8.5	2-9
TD4	8;3	95%	7	1-9
TD5	9;2	91%	8	2-9

Discussion

While a handful of studies have reported on speech sound accuracy in children with dysarthria due to CP, the present study explored vowel intelligibility in this population. In summary, more numerous and heterogeneous vowel intelligibility deficits were found in children with dysarthria than in typically-developing children. Additionally, a discrepancy in the relationship between transcription accuracy and ratings of ease of understanding was observed.

As promoting intelligibility is prioritized over increasing accuracy in speech treatment (Yorkston et al., 2010), findings on intelligibility deficits can guide treatment approaches. Vowel-specific effects on intelligibility could suggest vowel-specific treatment approaches (Lansford & Liss, 2014). For example, for an inaccurately perceived high-low vowel contrast, a treatment goal could be to increase distinctiveness between these classes of vowels. That this study did not find significant vowel-specific effects may also have relevance to treatment. If supported by future studies with greater power, a more global approach to increasing vowel intelligibility in children with dysarthria may be warranted.

Information on vowel production may be useful for showing changes as a function of intervention aimed at improving intelligibility in this population. Few reports have been published on intervention efficacy in dysarthria due to CP (Yorkston, 1996; Yorkston, Hakel, Beukelman, & Fager, 2007), and no randomized controlled studies have been performed on children with dysarthria (Pennington, Goldbart, & Marshall, 2003). The findings and potential implications for intervention are discussed below, although it is recognized that further research is needed in order to generalize to children beyond this small sample.

Our results, not surprisingly, indicated that children with spastic dysarthria due to CP produced vowels less intelligibly than typically-developing children. The discrepancy between transcription intelligibility and ratings of ease of understanding of vowels produced by children with dysarthria in this study suggests that factors other than intelligibility contribute to listeners' judgments of the intelligibility of dysarthric speech (Hustad, 2008). CP2, whose (frequently whispered) speech was least intelligible as defined by transcription accuracy, was not judged least intelligible. This discrepancy may suggest that unintelligible utterances caused by articulatory placement errors are judged more harshly (and may lead to assessments of greater severity) than those caused by poor breath support.

Central and peripheral vowels were produced with approximately the same intelligibility, consistent with Tjaden et al.'s (2005) finding of central vowels also affected in adults with dysarthria due to ALS; however, when vowels were not intelligible, both groups of children tended to produce more central vowels than peripheral vowels. Thus, centralization characterized vowels produced in error by the children with dysarthria and TD and is consistent with findings of the relationship between lower word intelligibility and reduced vowel space area in children with dysarthria (Higgins & Hodge, 2002).

In our exploratory study, transcription intelligibility did not differ as a function of the target vowel. Moreover, although low and back vowels were the most difficult vowels for listeners to decode, this finding did not reach statistical significance. Therefore, it is premature to suggest that certain vowels are consistently the least intelligible or require special attention in intervention. In perceptual training studies, targeting a small set of vowels at a time in adults (Nishi & Kewley-Port, 2007; 2008) has yielded distortions in perception of the "untreated" vowels. Thus unless larger studies confirm such findings, attention to a child's entire vowel inventory may also be advised for improving his or her vowel production in that language.

Such intervention may include treatment that indirectly produces vowel differentiation or direct production practice with vowels. As an example of indirect approaches affecting vowel production in adults with dysarthria, Tjaden and Liss (1995) posited that the decreased articulatory errors found after using breath group strategies in sentence production were attributable, in part, to reduction in instances of whispering vowels, although this technique was not directly aimed at improving vowel production. Similarly, Lee Silverman Voice Treatment LOUD (LSVT® LOUD) for hypokinetic dysarthria due to Parkinson Disease yielded a larger vowel space area and greater intelligibility (Sapir, Spielman, Ramig, Story, & Fox, 2007), although healthy loudness was the direct target of treatment, not vowel intelligibility. Dromey, Ramig, and Johnson (1995) further found vowel and word duration increases (along with greater F2 transition rate) following LSVT LOUD without direct vowel treatment. They suggest that the longer duration resulting from louder speech permits the tongue more time to reach its target.

If vowels are targeted directly, the vowel confusions revealed in this study suggest that an intervention goal may be to separate minimal pairs (e.g., "nut" and "knot") whose target vowels are distinctive, thereby reducing the talker's vowel overlap. Auditory word recognition models such as the Neighborhood Activation Model (Luce & Pisoni, 1998) might posit that a less degraded stimulus would provide more phonetic information to the listener, reducing the number of competing phonetic neighbors, and thereby yielding more efficient and accurate word recognition. The heterogeneity in vowel production, especially in the children with dysarthria, suggests that appropriate vowel intervention targets may differ from child to child. Speech strategies focusing on both the segmental and suprasegmental levels (Patel & Alexander, 2010) may be promising therapeutic approaches for increased intelligibility and speech naturalness in this population.

Less is known about treatment of pediatric dysarthria than adult dysarthria, although caution should be exercised in applying treatments based on adult models, as the nature of the child's speech disorder, its relationship to linguistic development and expression, and the mechanisms of change (Goffman, 2010; Kent, 2000) will likely be different from an adult's. The few studies of intervention for children with dysarthria using a systems-based approach focusing on respiration, phonatory control, phrase length, and speech rate (e.g., Levy et al., 2012; Levy, 2014; Pennington et al., 2013; Pennington, Smallman, & Farrier, 2006) have found promising improvement in intelligibility in children with dysarthria. Similarly, LSVT LOUD yielded benefits to ratings of articulatory precision and acoustic measures in this population (Fox & Boliek, 2012; Levy et al., 2012). LSVT LOUD and Speech Systems Intelligibility Treatment (SSIT; Levy, 2014) also resulted in greater overall intelligibility ratings and accuracy and larger vowel space area in some, but not all, of the children with dysarthria tested.

Limitations of this exploratory study include that only a subset of possible vowel contrasts were examined as perceived by two groups of listeners. The groups may have judged the children along different parameters, possibly contributing to the group differences found. Moreover, a small number of heterogeneous children of a large age range were tested. Variation in vowel production is expected even in TD. Lexical and neighborhood effects, although reduced by the use of minimal pair words in isolation, might also have played a role in the listeners' recognition and judgments of words (Luce & Pisoni, 1998).

We aimed to provide some data that would help set the stage for future work. Future directions include a study with more children with dysarthria producing real and nonsense words, likely revealing clearer patterns in the development of intelligibility in children with dysarthria and typically-developing children. Such information will not only supply more details regarding vowels that may be targeted during speech intervention, but will also provide baseline data for documenting changes in intelligibility as a function of speech treatment.

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Declaration of Interest

The authors report no declarations of interest.

References

Ansel, B. M. (1985). Acoustic predictors of intelligibility in cerebral palsied-dysarthric adults (Unpublished doctoral dissertation). University of Wisconsin-Madison, Madison, WI..

Ansel, B. M., & Kent, R. D. (1992). Acoustic-phonetic contrasts and intelligibility in the dysarthria associated with mixed cerebral palsy. *Journal of Speech and Hearing Research, 35*(2)*,* 296-308.

American National Standard Institute. (2010). *Specification for Audiometers.* ANSI Report No. S3.6-2010, New York, NY: ANSI.

Boersma, P., & Weenink, D. (2005). Praat: Doing phonetics by computer (Version 4.3.01) [Computer program]. Retrieved from http://www.praat.org

Byrne, M. (1959). Speech and language development of athetoid and spastic children. *Journal of Speech and Hearing Disorders, 24*(3), 231-240.

Carrow-Woolfolk, E. (1998). *Test for Auditory Comprehension of Language* (3rd ed.). Austin, TX: Pro-Ed.

Centers for Disease Control and Prevention. (2014). Cerebral Palsy (CP). Retrieved from http://www.cdc.gov/ncbddd/cp

Chung, H., Nearey, T. M., Hodge, M., Pollock, K. E., & Tucker, B. V. (2012). Preliminary statistical pattern recognition methods in the study of vowels produced by children with and without speech sound disorders. *Canadian Acoustics*, *40*(3), 18-19.

Dromey, C., Ramig, L. O., & Johnson, A. (1995). Phonatory and articulatory changes associated with increased vocal intensity in Parkinson disease: A case study. *Journal of Speech and Hearing Research*, *38*(4), 751–764.

DuHadway, C. M., & Hustad, K. C. (2012). Contributors to Intelligibility in Preschool- Aged Children with Cerebral Palsy. *Journal of Medical Speech Language Pathology, 20*(4), 1-5.

Fox, C. M., & Boliek, C. A. (2012). Intensive voice treatment (LSVT® LOUD) for children with spastic cerebral palsy and dysarthria. *Journal of Speech, Language, and Hearing Research, 55*(3), 930-945.

Fudala, J. B. (2001). *Arizona Articulation Proficiency Scale* (3rd ed.). Los Angeles, CA: Western Psychological Services.

Goffman, L. (2010). Dynamic interaction of motor and language factors in normal and disordered development. In B. Maassen & P. H. H. M. Van Lieshout (Eds.), *Motor speech control: New developments in basic and applied research* (pp. 137-152). New York, NY: Oxford University Press.

Havstam, C., Buchholz, M., & Hartelius, L. (2003). Speech recognition and dysarthria: A single subject study of two individuals with profound impairment of speech and motor control. *Logopedics Phonatrics Vocology*, *28*(2), 81-90.

Higgins, C. M., & Hodge, M. M. (2002). Vowel space area and intelligibility in children with and without dysarthria. *Journal of Medical Speech-Language Pathology, 10,* 271-277.

Hodge, M., & Gotzke, C. (2007). TOCS+ Recorder-Player Software – *TOCS+RM™ ver. 2.0.* Edmonton, AB: University of Alberta.

Hodge, M. M., & Gotzke, C. L. (2011). Minimal pair distinctions and intelligibility in preschool children with and without speech sound disorders. *Clinical linguistics & phonetics*, *25*(10), 853-863.

Hodge, M. M., & Gotzke, C. L. (2014). Criterion validity of the Test of Children's Speech Sentence Intelligibility Measures for children with cerebral palsy and dysarthria.

International Journal of Speech-Language Pathology, 16(4), 417-426.

Hustad, K. C. (2006). Estimating the intelligibility of speakers with dysarthria. *Folia Phoniatrica et Logopaedica, 58*(3), 217-228.

Hustad, K. C. (2008). The relationship between listener comprehension and intelligibility scores for speakers with dysarthria. *Journal of Speech, Language, and Hearing Research, 51*(3), 562-573.

Hustad, K. C. (2012). Speech intelligibility in children with speech disorders*. SIG 1 Perspectives on Language Learning and Education, 19*(1)*,* 7-11.

Kaufman, A. S., & Kaufman, N. L. (2004). *Kaufman Brief Intelligence Test-2 (KBIT-2)*. Minneapolis, MN: Pearson Assessments.

Kaufman, N. (1995). *Kaufman Speech Praxis Test for Children.* Detroit, MI: Wayne State University Press.

Kent, R. D. (2000). Research on speech motor control and its disorders: A review and prospective. *Journal of Communication Disorders, 33*(5)*,* 391-428.

Kent, R. D., Miolo, G., & Bloedel, S. (1994). The intelligibility of children's speech. *American Journal of Speech-Language Pathology, 3*(2)*,* 81-95.

Kent, R. D., & Rosenbek, J. C. (1983). Acoustic patterns of apraxia of speech. *Journal of Speech, Language, and Hearing Research, 26*(2), 231-249.

Kent, R., Weismer, G., Kent, J., & Rosenbek, J. (1989). Toward explanatory intelligibility testing in dysarthria. *Journal of Speech and Hearing Disorders, 54*(4), 482–49.

Kim, H., Hasegawa-Johnson, M., & Perlman, A. (2011). Vowel contrast and speech intelligibility in dysarthria. *Folia Phoniatrica et Logopaedica, 63*(4), 187-194.

Lansford, K. L., & Liss, J. M. (2014). Vowel acoustics in dysarthria: Mapping to perception. *Journal of Speech, Language, and Hearing Research*, *57*(1), 68-80.

Lee, J., & Hustad, K. C. (2013). A preliminary investigation of longitudinal changes in speech production over 18 months in young children with cerebral palsy. *Folia Phoniatrica et Logopaedica, 65*(1), 32-39.

Lee, J., Hustad, K. C., & Weismer, G. (2014). Predicting speech intelligibility with a multiple speech subsystems approach in children with cerebral palsy. *Journal of Speech, Language, and Hearing Research, 57*(5)*,* 1666-1678.

Leone, D., & Levy, E. S. (2015). Children's perception of conversational and clear American-English vowels in noise. *Journal of Speech, Language, and Hearing Research, 58*(2)*,* 213-226.

Levy, E. S. (2014). Implementing two treatment approaches to childhood dysarthria. *International Journal of Speech-Language Pathology, 16*, 344-354.

Levy, E. S., Ramig, L. O., & Camarata, S. M. (2012). The effects of two speech interventions on speech function in pediatric dysarthria. *Journal of Medical Speech-Language Pathology, 20*(4), 82-87.

Luce, P. A., & Pisoni, D. B. (1998). Recognizing spoken words: The neighborhood activation model. *Ear and Hearing, 19*(1)*,* 1-36.

Nickerson, R. S., & Stevens, K. N. (1980). Approaches to the study of the relationship between intelligibility and physical properties of speech. In J. Subtelny (Ed.), *Speech assessment and speech improvement for the hearing impaired* (pp. 338- 364). Washington, DC: A. G. Bell Association for the Deaf.

Nishi, K., & Kewley-Port, D. (2007). Training Japanese listeners to perceive American English vowels: Influence of training sets. *Journal of Speech, Language, and Hearing Research,* *50*(6), 1496-1509.

Nishi, K., & Kewley-Port, D. (2008). Nonnative speech perception training using vowel subsets: Effects of vowels in sets and order of training. *Journal of Speech, Language, and Hearing Research, 51*(6), 1480-1493.

Palisano, R., Rosenbaum, P., Walter, S., Russell, D., Wood, E., & Galuppi, B. (1997). Development and reliability of a system to classify gross motor function in children with cerebral palsy. *Developmental Medicine & Child Neurology, 39*(4), 214-223.

Patel, R., & Alexander, K. (2010). Effect of speaking rate on comprehension of prosodic intent in dysarthria. *Journal of Medical Speech Language Pathology, 18*(4)*,* 109-114.

Pennington, L., Goldbart, J., & Marshall, J. (2003). Speech and language therapy to improve the communication skills of children with cerebral palsy. *Cochrane Database of Systematic Reviews, 3*, 1-19. doi:10.1002/14651858.CD006937.pub2

Pennington, L., Smallman, C., & Farrier, F. (2006). Intensive dysarthria therapy for older children with cerebral palsy: Findings from six cases*. Child Language Teaching and Therapy, 22*(3), 255-273.

Pennington L., Roelant, E., Thompson, V., Robson, S., Steen, N., & Miller, N. (2013). Intensive dysarthria therapy for younger children with cerebral palsy. *Developmental Medicine and Child Neurology, 55*(5), 464-471.

Peterson, H. A., & Marquardt, T. P. (1981). *Appraisal and diagnosis of speech and language disorders.* Englewood Cliffs, NJ: Prentice-Hall.

Platt, L. J., Andrews, G., & Howie, P. M. (1980). Dysarthria of adult cerebral palsy: II. Phonemic analysis of articulation errors. *Journal of Speech and Hearing Research, 23*(1)*,* 41-55.

Platt, L. J., Andrews, G., Young, M., & Quinn, P. T. (1980). Dysarthria of adult cerebral palsy: I. Intelligibility and articulatory impairment. *Journal of Speech and Hearing Research, 23*(1), 28-40.

Sapir, S., Spielman, J. L., Ramig, L. O., Story, B. H., & Fox, C. (2007). Effects of intensive voice treatment (the Lee Silverman Voice Treatment [LSVT]) on vowel articulation in dysarthric individuals with idiopathic Parkinson disease: acoustic and perceptual findings. *Journal of Speech, Language, and Hearing Research, 50*(4), 899–912.

Tjaden, K., & Liss, J. M. (1995). The influence of familiarity on judgments of treated speech. *American Journal of Speech-Language Pathology, 4*(1), 39-48.

Tjaden, K., Rivera, D., Wilding, G. E., & Turner, G. (2005). Characteristics of the lax vowel space in dysarthria. *Journal of Speech, Language, and Hearing Research, 48*(3), 554-566.

Workinger, M. S., & Kent, R. D. (1991). Perceptual analysis of the dysarthrias in children with athetoid and spastic cerebral palsy. In C. A. Moore, K. M. Yorkston, & D. R. Beukelman (Eds.), *Dysarthria and apraxia of speech: Perspectives on management* (pp. 109-126). Baltimore, MD: Paul Brookes.

Yorkston, K. M. (1996). Treatment efficacy: Dysarthria. *Journal of Speech and Hearing Research, 39*(5)*,* S46-S57.

Yorkston, K. M., Beukelman, D. R., Strand, E. A., & Hakel, M. (2010). *Management of Motor Speech Disorders in Children and Adults*. Austin, TX: PRO-ED.

Yorkston, K. M., Hakel, M., Beukelman, D. R., & Fager, S. (2007). Evidence for effectiveness of treatment of loudness, rate or prosody in dysarthria: A systematic review. *Journal of Medical Speech-Language Pathology, 15*(2), xi-xxxvi.