Effects of Speech Cues on Acoustics and Intelligibility of Korean-speaking Children with Dysarthria

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Abstract

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The motor speech disorder of dysarthria is present in a substantial number of children with cerebral palsy (CP), leading to speech intelligibility deficits, which may negatively affect the children's communication and quality of life. Few studies to date have examined strategies for increasing intelligibility in children with dysarthria, and most have focused on English speakers. Thus, questions regarding the effects of speech cueing strategies in speakers of other languages are underexplored. The purpose of this study was to determine if (Korean translations of) two cues, "speak with your big mouth," targeting greater articulatory excursion, and "speak with your strong voice," targeting greater vocal intensity, would elicit changes in speech acoustics and intelligibility in Korean-speaking children with dysarthria secondary to CP. Fifteen Korean-speaking children with dysarthria repeated word- and sentence-level stimuli in habitual, big mouth, and strong voice conditions. Intelligibility was assessed through the ease-of-understanding (EoU) ratings and percentage of words correctly transcribed (PWC) by 90 blinded listeners. Results indicated significantly greater vocal intensity and greater utterance duration in the cued conditions, demonstrating the children's ability to vary their speech styles in response to the two cues. Furthermore, word-level EoU gains following both cues and sentence-level EoU gains following the strong voice cue suggest potential intelligibility benefits of the cues in this population. Gains in PWC were not statistically significant, and considerable variability in the children's responses to the cues was noted overall. These findings contribute to the limited knowledge base for speech-language pathologists working with Korean speaking children. The variability in responses points to the importance of assessing each child's stimulability to cues aimed to enhance intelligibility. Further clinical and theoretical considerations, including cross-linguistic implications, are discussed.

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Chapter 1: Introduction

The motor speech disorder of dysarthria is present in a substantial number of children with cerebral palsy (CP), with reports of prevalence in this population ranging from 21% to 90% (Mei et al., 2014; Nordberg et al., 2013). Dysarthria may be characterized by imprecise articulation, strained vocal quality, and reduced vocal intensity, among other speech characteristics (Duffy, 2019). In many children with dysarthria, the resulting speech intelligibility deficits create a barrier to communication (Pennington & McConachie, 2001), negatively affecting their social development and diminishing their quality of life (Colver et al., 2015; Dickinson et al., 2007; Fauconnier et al., 2009). Therefore, improving speech intelligibility is often a fundamental goal for this population.

Few studies to date have examined strategies for increasing intelligibility in children with dysarthria, and within this limited literature, most have focused on English speakers. Therefore, questions regarding the effects of such strategies in speakers of other languages remain particularly unexplored. Evidence of potentially differential responses to cueing and treatment are beginning to be documented in various linguistic populations (e.g., Levy et al., 2020; Moya-Galé et al., 2016; 2021). Thus, it is important to know which strategies may elicit intelligibility gains in speakers of the specific languages. Such information would serve as a foundation for improving intelligibility and quality of life in a larger number of children with diverse language backgrounds. We begin with a review of speech strategies studied primarily in English-speaking children with dysarthria secondary to CP (henceforth, "children with dysarthria") and suggest hypotheses for strategies to improve intelligibility in Korean-speaking children with dysarthria.

1.1 Speech strategies for children with dysarthria

Many children with dysarthria present with reduced vowel space area (VSA), which negatively impacts their intelligibility (DuHadway & Hustad, 2012; Higgins & Hodge, 2001; Lee & Hustad, 2013; Lee et al., 2014). Therefore, strategies targeting VSA expansion may increase the children's intelligibility. One strategy aimed to increase articulatory excursion, and thereby increase VSA, is to cue children with dysarthria to "speak with your big mouth" (henceforth "big mouth") (Levy et al., 2017). This big mouth strategy is similar to clear speech strategies (Picheny et al., 1985), which utilize hyper-articulation to enhance intelligibility in adults when their conversational partners have speech perception difficulties (Similjanić & Bradlow, 2009). Levy et al. (2017) found that cueing eight children with dysarthria to "speak with your big mouth" yielded a significant increase in word and sentence intelligibility. Relative to the children's habitual speech, the big mouth cue elicited an increase in blinded listeners' ease-of-understanding (EoU) ratings and word transcription accuracy (percent words correctly transcribed; PWC), along with a significant increase in utterance duration and sound pressure level (SPL). Therefore, cueing big mouth holds promise as a therapeutic strategy for enhancing intelligibility in children with dysarthria. The positive findings are consistent with the clear speech literature on adults with Parkinson's disease (PD) (Goberman & Elmer, 2005; Lam et al., 2012; Lam & Tjaden, 2016) and with amyotrophic lateral sclerosis (Turner et al., 1995).

Increasing vocal intensity is another strategy that may elicit intelligibility improvement in children with dysarthria. The increase in audibility and phonetic accuracy, as well as other positive effects on speech production, brought about by increasing vocal intensity (e.g., Levy et al., 2012; Sapir et al., 2007; Boliek & Fox, 2017; Fox & Boliek, 2012) may contribute to intelligibility gains. One speech strategy that uses a simple, child-friendly instruction to target intensity to cue children to “speak with your strong voice.” Levy and her colleagues found that in response to this strong voice cue, children with dysarthria increased their vocal SPL, as well as their word, and sentence intelligibility. Similarly, children with dysarthria have benefited from the 4-week intensive Lee Silverman Voice Treatment (LSVT LOUD®; Ramig et al., 2001) that targets healthy vocal loudness. Immediately after receiving LSVT LOUD, children with dysarthria exhibited a significant increase in SPL and intelligibility (Boliek & Fox, 2017; Fox & Boliek, 2012). The acoustic and perceptual gains from the strong voice cue and LSVT LOUD are consistent with the findings from past treatment studies targeting healthy vocal loudness in adults with dysarthria secondary to PD (e.g., Cannito et al., 2012; Levy et al., 2020). This suggests that such strategies also hold potential for improving intelligibility in individuals with dysarthria.

Furthermore, a recent treatment study reported positive results of the big mouth and the strong voice cues when they were combined in the treatment protocol of Speech Intelligibility Treatment (SIT; Levy et al., 2021). SIT is an intensive three-week treatment program that implements motor learning principles and aims to increase intelligibility of children with dysarthria (Levy et al., 2021). Children are trained to “speak with your big mouth and strong voice.”. Following SIT significant gains in story narrative EoU as well as increased communicative participation were seen in 17 American English (AE)-speaking children with dysarthria, with the gains maintained at 6 weeks post-treatment. Thus, this study provided preliminary evidence for the use of the big mouth and the strong voice strategies in treatment to yield immediate and long-term intelligibility changes; however, the combination of these strategies renders it difficult to know the specific effects produced by each strategy.

Speech rate reduction may arguably be another beneficial strategy for children with dysarthria, although mixed findings have been reported regarding its effects on intelligibility.

Both the big mouth and the strong voice cues resulted in a significant reduction in speech rate (Levy et al., 2017). Another way to achieve rate reduction is through the insertion of inter-word pauses. Inserting pauses during sentence production may improve intelligibility by reducing coarticulation, delineating word boundaries, and facilitating lexical segmentation to lessen the phonemic ambiguity experienced by listeners (McAuliffe et al., 2014; Tjaden & Wilding, 2004;). Sakash et al. (2020) implemented a slow speech cue via modeling and software that provided visual cues to insert inter-word pauses. In response to this cue, children with moderate to severe dysarthria demonstrated significant intelligibility gains, with greater improvements for sentences containing more than four words. The positive effects of slow speech on intelligibility are consistent with the results of the big mouth and the strong voice cues (Levy et al., 2017), as well as with the results of several studies on rate reduction in the adult dysarthria literature (Hustad & Sassano, 2002; McAuliffe et al., 2017; McHenry, 2003; Pilon et al., 1998; Yorkston et al., 1990). However, other studies have reported decreased intelligibility associated with reduced speech rate in children with dysarthria (e.g., Patel et al., 2012; Allison & Hustad, 2018; Lee et al., 2014). For example, Patel et al. (2012) found that intelligibility (as measured by listeners' transcription accuracy) was lower for words that were elongated in duration. Slower speaking rate may reduce prosodic contrasts, and thereby, negatively impact communication effectiveness and naturalness of children's speech. The mixed findings on rate reduction strategies may point to factors such as dysarthria severity, length of utterance, and cueing method, modulating the effectiveness of such strategies on intelligibility of children with dysarthria.

1.2 Comparing speech strategies across languages

As described, speech strategies targeting greater articulatory excursion, increased vocal loudness, and sometimes speech rate reduction, increase intelligibility in English-speaking children with dysarthria. However, because the research on this topic has largely been limited to this language group, it is unclear whether similar effects can be expected in children who speak languages other than English.

Recent cueing and treatment studies examining the effects of the big mouth and strong voice strategies in French-speaking children with dysarthria suggests some commonalities and differences in the performance of AE and French speakers. When Levy et al. (2020) cued 11 Belgian French-speaking children with dysarthria to speak with their big mouth and their strong voice, significant gains in duration and SPL were observed following both cues, consistent with the findings in AE-speaking children with dysarthria (Levy et al., 2017). However, gains in intelligibility differed. Whereas the greatest intelligibility improvement was seen in the big mouth condition in AE-speakers, equivalent gains were observed in response to the two cues at the word level in French speakers. Furthermore, when 10 Belgian French-speaking children with dysarthria were randomized to receive either the SIT or a physical therapy (PT) treatment, immediate post-treatment results revealed an increase in listeners' orthographic transcription accuracy of story narratives produced by the children in the SIT group only (Moya-Galé et al., 2021). The increased intelligibility post-SIT is similar to the gains seen in AE-speaking children (Levy et al., 2021); however, the extent of improvement varied between the two groups.

The differential intelligibility gains observed between AE- and French-speaking children with dysarthria may reflect, to some extent, the intrinsic differences across studies (e.g., children's ages and dysarthria characteristics and severity). Nevertheless, the findings also raise the question of whether appropriate strategies for increasing intelligibility differ across languages and therefore need to be optimized based on the particular phonological characteristics of each language. Alternatively, certain strategies may be effective across languages because of the universal physiological nature of motor disturbances in dysarthria, and therefore, of responses to such strategies. Larger and more numerous studies across languages may clarify whether such gains, and to what extent, can be expected in children who speak a language other than English or French.

1.3 Hypotheses regarding the effects of speech strategies across languages

Three hypotheses are proposed regarding the acoustic and intelligibility changes elicited by the big mouth and the strong voice cues across different language groups. The hypothesis of differential (language-specific) impact of particular language on the outcomes of speech strategies relies on the phonological dissimilarities across languages. For example, the big mouth cue, which elicited increases in sentence duration and intelligibility in AE-speaking children, did not yield significant sentence-level intelligibility gains in French-speaking children (Levy et al., 2017; 2020). The difference may relate to prosodic constraints of French. In French, stress is signaled within each utterance, whereas in AE and other stress-timed languages, stress is indicated within each word. In addition, the syllable that receives stress in French is constrained by its position—the stress is on the final syllable of an utterance (Duez, 2014). Therefore, French-speaking children may have produced changes in only the final or penultimate syllable of an utterance via a stressed syllable of greater length and fundamental frequency variation, resulting in intelligibility benefit to only words that are at the end of a phrase. In contrast, the AE-speaking children may have produced more distinct speech sounds in each of the words within a sentence following the big mouth cue, resulting in improved sentence intelligibility overall.

Alternatively, the hypothesis of more universal (language-independent) benefits posits that neuromotor disturbance causing the speech disorder is physiological and therefore, universal

(Pinto et al. 2017). Thus, strategies addressing or even counteracting these effects might benefit children with dysarthria, regardless of their language background. Indeed, intelligibility improvement associated with increased vocal loudness has been observed in many languages (e.g., cerebral palsy: English [Levy et al., 2017, 2020], French [Levy et al., 2020], Korean [Kim, 2002]; Parkinson's disease: French [Sauvageau et al., 2015], Mandarin [Lee & McCann, 2009, Hsu et al., 2019], Spanish [Moya-Galé et al., 2018]). Similarly, the effects of VSA expansion on intelligibility may also be universal, as reduced VSA is characteristic of dysarthria that negatively affects intelligibility in many language groups (e.g., Mandarin: Mou et al., 2019; Korean: Kim et al., 2014).

And finally, we hypothesize that some speech strategies may be universally beneficial, but the extent of improvement could be language-specific. For example, while strategies that target VSA expansion may increase intelligibility across languages, greater intelligibility gains may be expected in languages that have a larger number of vowels occupying a denser vowel space, such as AE, than in languages that have far smaller vowel inventories, such as Korean. Expanding the VSA in AE would be expected to increase the acoustic distance between vowel pairs such as /ʃip/ vs. /ʃɪp/, rendering the vowels more distinct. In contrast, expanding the VSA in Korean would not be expected to impact the distinctiveness of the vowels in the Korean words (e.g., /kil/ vs. /kɯl/) to the same extent, as these vowels are distant in the acoustic vowel space. Further studies conducted in various languages may offer a more comprehensive understanding of the language-specific and more universal effects of the speech strategies. Such information may impact treatment directions for children of a wider range of language backgrounds, including the population of Korean-speaking children with dysarthria.

1.4 Speech strategies for Korean-speaking children with dysarthria

Korean is spoken by 75 million individuals in more than 190 countries (Kim & Pae, 2007). The incidence of CP in Korea is approximately 2.5 per 1,000 live births (Kim et al., 2018), similar to the incidence of CP in the United States and Europe (Paneth et al., 2006; Froslev-Friis et al., 2015; SCPE, 2002). Not surprisingly, in the substantial number of Korean-speaking children with CP, dysarthria has been reported as one of the most common accompanying impairments (Yim et al., 2017). Therefore, it is important to examine the effectiveness of speech strategies for this population.

Strategies to improve intelligibility in Korean-speaking children with dysarthria are currently understudied. Furthermore, to the authors' knowledge, no cueing study exists for this population. Most treatment approaches to date have focused on implementing non-speech oral motor exercises (OME), and report post-treatment increases in maximum phonation time, acoustic vowel space, and accuracy of vowel production in nonsense syllables (e.g., Lee & Yoo, 2008; Kim et al., 2008; Kim & Paek, 2017). For example, Kim and Paek (2017) provided OME treatment involving sensory stimulation and chin, lip, and tongue exercises (Kim & Paek, 2017) to two Korean-speaking children with dysarthria due to CP. Following this treatment, the children's intelligibility of nonword CV syllables increased, as measured by the percentage of vowels and consonants correctly transcribed by unfamiliar listeners. However, questions arise regarding the effectiveness of oral motor exercises (Lof & Watson, 2008) and the generalizability of tasks not involving real word and sentence production. Therefore, determining speech strategies that enhance word- and sentence- intelligibility may help build a scientific foundation on which to develop speech treatments for Korean-speaking children with dysarthria.

1.5 Study aims and hypotheses

This study investigated the effects of two speech cueing strategies on the acoustic characteristics and intelligibility of speech produced by Korean-speaking children with dysarthria secondary to CP. The effects of the cues were evaluated at word level and sentence level, as described in the Method section. Acoustic measures of speech were examined as indications that children were able to follow directions and make the modifications that were intended through each strategy.

The two cues, “speak with your big mouth” and “speak with your strong voice,” were designed to target increased articulatory excursion and vocal loudness, respectively. These two cueing strategies were selected because of the significant intelligibility gains they have yielded in AE- and French-speaking children with dysarthria (Levy et al., 2017; 2020). Furthermore, because dysarthria characteristics reported in Korean-speakers are similar to those of AE-speakers, including imprecise articulation, slow speech rate, variable vocal intensity, and reduced articulatory vowel space area (e.g., Park et al., 2010; Kim et al., 2014; Sim & Park, 1998), the big mouth and the strong voice cueing strategies may also be beneficial for Korean-speaking children with dysarthria. Examining the effects of each cue would also help determine whether one or both cue(s) would be beneficial for this population.

It should be noted that cueing studies, such as the present one, examine speech immediately after cues are provided. This enables a direct comparison of responses to various cues (e.g., Levy et al., 2017; 2020; Sakash et al., 2020; Tjaden & Wilding, 2004), and the results may contribute to an important research base for developing appropriate treatment approaches. In the present study, if both cues lead to significant intelligibility gains, then a treatment implementing a combination of the two cues, such as SIT (Levy et al., 2021), may hold potential as a therapeutic approach for increasing intelligibility in Korean-speaking children with dysarthria.

It was hypothesized that the big mouth cue would yield significant increases in utterance duration and intelligibility in the Korean-speaking children with dysarthria, as was found for AE- and French-speaking children with dysarthria in Levy et al. (2017; 2020). Expansion of the VSA following the big mouth cue was also anticipated because VSA expansion has been reported following strategies with similar aims of increasing articulatory excursion (e.g., Lam & Tjaden, 2016; Tjaden et al., 2013). Significant gains in intelligibility were also expected following the big mouth cue, consistent with prior findings (Levy et al., 2017; 2020); however, the extent of intelligibility gains might differ from these previous studies due to the phonological and prosodic characteristics that are specific to the Korean language. Compared to AE, Korean has fewer monophthongs and contrastive vowel pairs (e.g., front-back and high-low distinctions) in close proximity within the articulatory working space (Yang, 1996). Therefore, any VSA expansion may have less of an impact on increasing intelligibility in Korean speakers than in speakers of AE. Furthermore, the big mouth strategy may elicit smaller intelligibility gains in speakers of languages with syllable-timed rhythmic structure (Levy et al., 2020), such as French and Korean.

It was further hypothesized that in response to the strong voice cue, vocal SPL would increase (Fox & Boliek, 2012; Levy, 2014; Levy et al. 2012, 2017), with possible increases in utterance duration and VSA, as well (Tjaden et al., 2013). Furthermore, an increase in intelligibility was expected, as documented in AE-speaking and French-speaking children with dysarthria (Levy et al., 2017; 2020).

Chapter 2: Methods

This study was approved by the Institutional Review Boards at Teachers College, Columbia University in New York, and at Ewha Womans University in Seoul, South Korea.

2.1 Participants

2.1.1. Children with dysarthria

A total of 19 Korean-speaking children with CP, as diagnosed by a rehabilitation medicine physician, participated in the study. They were recruited through flyers posted in special education centers and rehabilitation institutions in Seoul, Korea. Final analysis included data collected from 15 children (11 males, 4 females; mean age = 11;11 years, SD = 4;3 years). Results from four children were excluded due to the children's refusal to comply or difficulty in completing all tasks for the study. All children included in the analysis were native speakers of Korean and reportedly did not speak another language. Inclusion criteria were: (1) use of speech as primary mode of communication, (2) passing a bilateral pure-tone hearing screening at 25 dB HL at 500, 1000, 2000, and 4000 Hz, and (3) ability to follow simple task-related directions, including repeating short phrases (Fox and Boliek 2012; Levy et al., 2017, 2020).

Details regarding the children's characteristics, including Gross Motor Function Classification System (GMFCS, Palisano et al., 1997) scores, are listed in Table 1. All children presented with dysarthria secondary to spastic or dyskinetic CP. The second author, a certified speech-language pathologist (SLP) in Korea, determined the characteristics and severity of dysarthria based on clinical evidence of impairment in at least two of the speech subsystems (Fox & Boliek 2012, Lee et al., 2014). Additionally, the first and third authors, also certified Korean-English bilingual SLPs, listened to each child's speech recorded during testing in order to reach a consensus on the characteristics and severity of the dysarthria. To determine the children's ability to perform all study tasks adequately, the second author evaluated the children's behavior during screening, utilized parental reports, and consulted with the children's physical therapists when necessary. Informal assessment through conversation and a receptive language subtest from the norm-referenced Korean Receptive and Expressive Vocabulary Test (REVT, Kim et al., 2020) were used to assess the children's receptive language skills. The family of each participating child was paid 20,000 KRW ($18 USD) for their participation.

Table 1. Participant characteristics of the children with dysarthria secondary to cerebral palsy.

Child	Age	Sex	Diagnosis	GMFCS	Dysarthria Severity	Language
CP01	8;4	M	spastic	IV	mild-moderate	delayed
CP02	9;6	M	spastic	II	mild-moderate	WNL
CP03	9;5	M	spastic	III	mild-moderate	WNL
CP04	18;4	M	dyskinetic	II	moderate	delayed
CP05	18.3	M	spastic	II	mild-moderate	WNL
CP06	11;10	M	ataxic	III	mild-moderate	WNL
CP07	18;0	M	spastic	IV	severe	delayed
CP08	14;9	M	dyskinetic	V	severe	delayed
CP09	16;7	M	spastic	III	mild	WNL
CP10	5;3	M	mixed[a]	IV	mild-moderate	delayed
CP11	11;8	F	spastic	II	moderate-severe	WNL
CP12	16;8	F	spastic	II	mild	WNL
CP13	9;5	F	spastic	II	mild	WNL
CP14	7;5	M	spastic	II	mild	WNL
CP15	10;0	F	spastic	IV	mild	WNL

Note. WNL = within normal limits; GMFCS = Gross Motor Classification System.
[a]Mixed dyskinetic and spastic.

2.1.2. Adult listeners

A total of 97 Korean-speaking adults were recruited to participate in the intelligibility assessment (listening tasks). Results from seven listeners were excluded, six due to technical difficulties during data collection and one due to bilingual background. The final analysis was thus completed using data from 90 listeners (89 females, 1 male; age range = 19;1 – 40;0 years, mean = 26;10 years, SD = 6;8 years). Listeners were recruited from the Seoul Metropolitan area in Korea through Ewha Womans University and passed a bilateral pure-tone hearing screening at 25 dB HL for 500, 1000, 2000, and 4000 Hz. They reported no significant history of speech, language, learning, cognitive, or auditory disorders, and no extensive contact with individuals with motor speech disorders. They were compensated 10,000 KRW ($9 USD) for their participation.

2.2 Stimulus acquisition and selection

2.2.1. Speech stimuli

Word- and sentence-level stimuli were developed by the first author to include a representative range of vowels and consonants in the Korean phonetic inventory. The stimuli were also designed to be age-appropriate in terms of vocabulary, morphosyntax, and syllable length. Stimuli were recorded as part of a larger study on speech production in Korean-speaking children with dysarthria secondary to CP.

The word-level task contained 21 contrastive monosyllabic real words, including /t^{h}al/, /tal/, /sal/, /san/, /k^{h}oŋ/, and /koŋ/. (A complete list can be found in Appendix A.) These contrastive words were embedded in the carrier phrase "*Dashi* CVC *haeyo"* [Say CVC again] in order to approximate the continuous speech characteristics of children's typical conversational speech (Levy et al., 2017). For the sentence task in the current experiment, three sentences were included: /pada borʌ kajo/ [Let's go to the ocean]; / tɕa tɕaŋ mjʌn kok sikjʌ/ [Order the noodles]; /kɯn baɥika boyjʌ/ [I see a big rock].

2.2.2. Speech recording procedure

Recording took place in a quiet room at Ewha Womans University and was completed in a single session for each child, with the exception of one child who required two sessions due to fatigue. On average, the recording took one hour, ranging from 50 minutes to 2 hours. During the recording session, children sat at a table, diagonally across from the experimenter. A SONY ICD-UX512F IC audio recorder was placed on the table 10 cm from the child. Given that vocal intensity was a variable of interest for this study, a careful calibration procedure was completed at the beginning and end of each recording session. For calibration, the experimenter played a pure tone through a generator (Online Tone Generator; https://www.szynalski.com/tone-generator) placed 10 cm from the microphone and noted the SPL measured by a sound level meter (Decibel X: dB Sound Level Meter; phone application version) adjacent to the audio recorder. Input level remained unchanged throughout all of the recordings. Stimuli were recorded at a sampling rate of 44.1 kHz with 16-bit resolution on a mono channel.

Children were asked to say the word and sentence stimuli in three different speaking conditions: habitual, big mouth (BM), and strong voice (SV). For the habitual condition, children were asked to speak as they normally do. For the BM and the SV conditions, they were instructed to "speak with a big mouth" and "speak with a strong voice," respectively. Verbal and visual instructions, cues, and experimenter modeling were provided to the children throughout the recording session. To ensure consistency of modeling across children, during the recording session, children listened and responded after the pre-recorded stimuli created by an adult native Korean-speaker. These stimuli were played through the Realtek High-Definition audio speakers in the Samsung NT530U3B Laptop placed at a consistent distance of 80 cm from the child. Additional instructions were provided as needed to remind the children of the two speech strategies. If a child did not repeat the utterance or produced an incomplete response, the experimenter gave them verbal reminders and replayed the recorded stimuli. In addition, visual aids were provided that consisted of a photo of a character with an open mouth (BM condition) and a character with a loudspeaker (SV condition). If extraneous noise (e.g., siren, alarm) occurred during the children's production, the experimenter paused the recording until the noise subsided, and then replayed the pre-recorded model stimuli. Verbal encouragement and breaks were provided when the children appeared fatigued.

All children completed the habitual condition first to rule out potential carryover effects (McAuliffe et al., 2014; Tjaden & Wilding, 2004). The order of the two experimental conditions was counterbalanced across children. Short break was provided between conditions.

2.2.3. Intelligibility assessment

All 90 listeners completed two listening tasks, the "word" listening task and the "sentence" listening task, in a quiet room at Ewha Womans University. Assessment at the word level involved ease-of-understanding ratings (EoU) and orthographic transcription of words (percentage of word correctly transcribed; PWC) in the same carrier phrase, with no semantic or syntactic cues provided. EoU allowed a more subjective assessment of whether the listener perceived speech to be easier to understand following the cues. The transcription analysis permitted a relatively objective measurement of intelligibility (Hustad, 2007). Assessment at the sentence level involved EoU ratings only because the same three (somewhat predictable) sentences were repeated across the three speaking conditions; thus, orthographic transcriptions would not have been appropriate.

Custom-developed software (Chang & Chang, 2015) programmed in MATLAB (Version R2015b) was used to present the children's utterances and collect listener responses. The recordings of the children's utterances were played through the laptop speaker placed 80 cm from the listener (Hall, 1966). Furthermore, to present the stimuli at the children's original vocal intensity level, the SPL of the calibration tone was reproduced at 10 cm from the laptop speaker prior to the intelligibility assessment. A familiarization procedure preceded each of the experimental tasks. Familiarization stimuli consisted of recordings of utterances produced by children with dysarthria not included in the current experiment.

Listeners were divided into 5 groups, with 18 listeners in each group. For the word listening task, each listener was assigned randomly to listen to the word-level stimuli (i.e., monosyllabic words embedded in a carrier phrase) produced by one child. This way, the task better represented everyday listening situations listeners generally listening to one child at a time during conversation) and allowed for an observation of within-speaker differences as a function of the cueing strategy (Levy et al., 2017). Furthermore, listening to only one child provided consistency for listeners throughout the task and minimized the effects of multi-speakers on perceptual processing (e.g., Mullennix et al., 1989). In total, each listener rated and transcribed 21 target words in a carrier phrase, as well as three stimuli randomly chosen from the target for reliability purpose.

For the sentence listening task, each listener group rated sentences produced by three children who were randomly assigned to the group, with no overlap of children between the groups. In total, each listener listened rated 27 stimuli sentences and three randomly chosen reliability sentences.

Task instructions were provided verbally and in written form, and the listeners were informed that all utterances consisted of real words. All stimuli were played only once to the listeners, with no option for replay. Listeners required approximately 45 to 60 minutes to complete the experimental tasks.

2.2.3.1. Task 1: Word-level intelligibility assessment

For the word-level intelligibility assessment, each listener heard 21 different single words in a carrier phrase produced by one child (seven words x three speaking conditions: habitual, BM, SV), with no word repeated across conditions, in order to avoid learning effects (Wilson et al., 2003). Approximately 10% of the stimuli were replayed at the end of the task for reliability. After being presented with the target word in the carrier phrase, listeners were asked to rate how easy the child's speech was to understand (EoU). In addition, they were also instructed to transcribe orthographically the word they heard (PWC). Listeners provided their ratings on a 9-cm visual analog scale (VAS) with anchor points "difficult" and "easy" by sliding a rectangular cursor between the two anchors (Levy et al., 2017). The anchor "difficult" corresponded to 0 and "easy" corresponded to 100, with placements between the two anchors corresponding to scores between these endpoints. The scores corresponding to the placement of the cursor were not visible to listeners. The final data included two EoU ratings and PWC (one from each of two listeners) of each word spoken by a child in each of the three speaking conditions.

2.2.3.2. Task 2: Sentence-level intelligibility assessment

For the sentence-level intelligibility assessment, each listener heard three children's production of sentences in the three speaking conditions (habitual, BM, SV) and judged how easy each sentence was to understand. Listeners' sentence EoU ratings were collected on a VAS. Each listener heard a total of 27 sentences (three children × three sentences × three conditions), with approximately 10% of the stimuli replayed at the end of the task for reliability. The sentences were blocked by child to minimize effects of multiple speakers (Mullennix et al., 1989) and randomized within the child block. The final sentence EoU data included 18 ratings for each sentence in each condition for each child. Orthographic transcriptions of the sentences were not collected because the sentences were predictable across children (i.e., same three sentences were uttered by all of the children).

2.3 Data analysis

2.3.1. Acoustic measures

Speech acoustic measures were analyzed to objectively assess for the changes in children's speech that were elicited by the BM and SV cues. Three acoustic measures were examined in the habitual, BM, and SV conditions: (a) duration and/or articulation rate, (b) VSA, and (c) SPL. Articulation rate was determined for sentences only, as this measure was calculated based on syllables produced per second. (Stimuli in the word listening task were all one-syllable words; therefore, word duration, rather than articulation rate, was measured.) Words and sentences were manually segmented and analyzed by a research assistant and the first and third authors. The onset and offset boundaries of each utterance were determined by the beginning and end of acoustic energy (Klatt, 1975; Levy & Law, 2010). All measures were obtained with a combination of the waveform and wideband spectrogram in Praat (Boersma & Weenink, 2020).

Duration was measured as the time between the onset and offset. Articulation rate was defined as the rate of speech (in syllables per second) excluding silent periods of greater than 200 ms within the sentence boundaries (Allison & Hustad, 2018). Therefore, pauses greater than 200 ms between the onset and offset boundaries were removed when obtaining sentence duration for the purpose of calculating articulation rate. Subsequently, the pause-excluded sentence duration was divided by the number of syllables in the sentence to obtain the syllables per second measurement (Allison & Hustad, 2018; Darling-White et al., 2018; Levy et al., 2021).

Vocal intensity was represented by the average SPL of each utterance within the onset and offset boundaries, as input level remained unchanged throughout the recording sessions. VSA was derived from the first (F1) and second (F2) formant frequencies of three corner vowels (/a/, /i/, /u/), which represent the extreme positions in a talker's articulatory vowel space (Lindblom, 1990; Turner et al., 1995; Sim & Park, 1998). F1 and F2 were measured at the temporal midpoint of the vowel (Hillenbrand et al., 1995). The following equation (Kent & Kim, 2003) was used to compute the VSA:

$$\mathrm{VSA} = \mathrm{ABS}\{[F1_i * (F2_a - F2_u) + F1_a * (F2_u - F2_i) + F1_u * (F2_i - F2_a)]/2\}$$

ABS indicates absolute value, $F1_i$ denotes the F1 value of vowel /i/, and other subscripts follow the same convention. In consideration of age and gender effects, VSA results were converted to a log scale (Nearey, 1992) for statistical analysis.

2.3.2. Intelligibility

For measures of intelligibility, three sets of data were analyzed: (1) word EoU ratings, (2) PWC, and (3) sentence EoU ratings. Mean EoU ratings were calculated by averaging the listener ratings per utterance. For 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.

2.4 Statistical analysis

Linear and binomial mixed effects analyses followed by post hoc pairwise comparisons with Bonferroni corrections were employed to examine the effect of speaking condition upon duration, articulation rate, VSA, SPL, EoU ratings, and PWC at the group level. Models were linear for all measures except PWC (words correctly/incorrectly transcribed), for which the model was binomial. Speaking condition (habitual, BM, SV) was the only predictor variable. For duration, articulation rate, VSA, and SPL, models included random effects of speakers (children). For PWC and EoU, random effects of listeners and speakers were included. Linear models were kept in their original scale because the dependent measures displayed approximately normal distributions. No data were excluded as there were no extreme values.

2.5 Reliability

2.5.1. Acoustic measures

A second judge (i.e., third author) randomly selected and manually re-checked 20% of the children's words and sentences. Reliability was indexed using Pearson product–moment correlations and absolute measurement errors. At the word level, the correlation between the first and second measurements of SPL was .98 (mean absolute difference measure = 0.21 dB, SD = 0.24 dB). The correlation between the first and second duration measures was .96 (mean absolute difference measure = 0.09 s, SD = 0.04 s). For VSA, the correlation between the formant values determined by the first and second judges was .90 (mean absolute difference measure = 122 Hz, SD = 59 Hz).

At the sentence level, the correlation between the first and second measurements was .99 for SPL (mean absolute difference measure = 0.17 dB, SD = 0.06 dB) and .98 for duration (mean absolute difference measure = 0.14 s, SD = 0.09 s). For sentence-level VSA, the correlation between the formant values determined by the first and second judges was .89 (mean absolute difference measure = 179 Hz, SD = 82 Hz).

2.5.2. Intelligibility

Intra- and inter-listener reliability of EoU and PWC were calculated via intraclass correlation coefficient (ICC). A two-way mixed model (with random listener effects and fixed measure effects) was used to determine the absolute agreement and consistency of ratings among listeners. For intra-listener reliability, 10% of the sentences and words were selected randomly and presented to each listener at the end of the task. For EoU at word level, the single measures ICC was .80 (95% CI [.77, .83]) and the average measures ICC was .85 (95% CI [.83, .87]). For EoU at sentence level, the single measures ICC was .83 (95% CI [.80, .87]) and the average measures ICC was .85 (95% CI [.81, .89]) for word EoU. For PWC, single measures ICC was .90 (95% CI [.87, .93]) and the average measures ICC was .93 (95% CI [.91, .95.]). All measures suggest good intra-listener reliability.

For the inter-listener reliability, average ICC (aggregate listener performance) was obtained as the primary measure of agreement among listeners (e.g., Tjaden et al, 2014). Each ICC was determined for a group of 18 listeners because they were grouped together to rate three children's speech (a total of 90 listeners divided into five groups). For EoU at word level, the average ICC ranged from .75 (95% CI [.73, .77]) to .82 (95% CI [.79, .85]). For EoU at sentence level, the average ICC ranged from .85 (95% CI [.81, .89]) to .89 (95% CI [.86, .92]). Both suggest good inter-listener reliability. For PWC, the average ICC ranged from .90 (95% CI [.88, .92]) to .96 (95% CI [.93, .99]), suggesting good to excellent inter-listener reliability. All ICC were statistically significant ($p < .05$).

Chapter 3: Results

3.1 Acoustic changes across speaking conditions

3.1.1. Word level

Mean group data for duration, VSA, and SPL across the three (habitual, big mouth, and strong voice) speaking conditions are listed in Table 2. Linear mixed effects analysis revealed significant main effects of speaking condition for both duration ($F(2, 799) = 164.37$, $p < .001$) and SPL ($F(2, 799) = 72.10$, $p = .02$). Post hoc pairwise comparisons with Bonferroni correction showed that word duration was significantly longer in the BM condition than the habitual or SV conditions (both $p < .001$). Duration was also significantly longer in the SV condition relative to the habitual condition ($p < .001$). Word SPL was significantly greater in the SV condition than in the habitual or BM conditions (both $p < .001$). SPL in the BM condition was also significantly greater than in the habitual condition ($p < .001$). Gains found in VSA in BM and SV conditions did not reach significance at the word level, $F(2, 28) = 2.30$, $p = .119$.

Table 2. Average word duration, vowel space area (VSA), and sound pressure level (SPL) of the speech of 15 children with dysarthria in the three speaking conditions (Habitual, Big Mouth, and Strong Voice).

	Habitual (SD)	**Big Mouth (SD)**	**Strong Voice (SD)**
Duration (sec)	0.37 (0.15)	0.52 (0.16)**	0.44 (0.17)**
VSA (in log)	4.91 (0.51)	5.13 (0.34)	5.03 (0.60)
SPL (dB)	79.52 (4.79)	80.67 (3.48)**	82.41 (3.30)**

Note. SD = standard deviation; sec = seconds; VSA = vowel space area; SPL = sound pressure level; dB = decibels.
**$p < .001$. Asterisks indicate significant differences compared to Habitual.

3.1.2. Sentence level

Table 3 presents mean group acoustic data for sentence duration, VSA, and SPL across the three speaking conditions. Consistent with the results at word level, there were significant effects of speaking condition for both duration ($F(2, 116) = 15.39$, $p < .001$) and SPL ($F(2, 115.08) = 13.49$, $p < .001$). Post hoc analyses confirmed that duration was significantly longer in the BM condition than either the habitual ($p < .001$) or the SV ($p = .008$) condition. Additionally, duration in the SV condition was significantly longer than in the habitual condition ($p = .046$). Similarly, there was a significant effect of condition on articulation rate, $F(2, 116) = 10.21$, $p = .002$, with post hoc pairwise comparisons revealing a significant reduction in rate following BM relative to both the habitual ($p < .001$) and SV ($p = .001$) conditions. Rate was also significantly reduced in the SV condition compared to habitual ($p = .021$). Sentence SPL was significantly greater in the SV condition relative to the habitual ($p < .001$) and BM ($p = .015$) conditions; however, SPL gains in the BM condition did not reach significance ($p = .063$). Furthermore, gains in VSA in the BM and SV conditions did not reach significance $F(2, 28) = 2.95$, $p = .069$.

Table 3. Average sentence duration, articulation rate (AR), vowel space area (VSA), and sound pressure level (SPL) of the speech of 15 children with dysarthria in the three speaking conditions (Habitual, Big Mouth, and Strong Voice).

	Habitual (SD)	Big Mouth (SD)	Strong Voice (SD)
Duration (sec)	2.09 (0.80)	2.91 (0.97)**	2.46 (1.42)*
AR (syllables/sec)	3.49 (0.94)	2.51 (0.57)**	3.16 (0.83)*
VSA (in log)	4.95 (0.56)	5.15 (0.59)	4.98 (0.67)
SPL (dB)	78.21 (4.69)	79.37 (3.67)	80.82 (3.74)**

Note. SD = standard deviation; sec = seconds; VSA = vowel space area; SPL = sound pressure level; dB = decibels.
*$p < .05$; **$p < .001$. Asterisks indicate significant differences compared to Habitual.

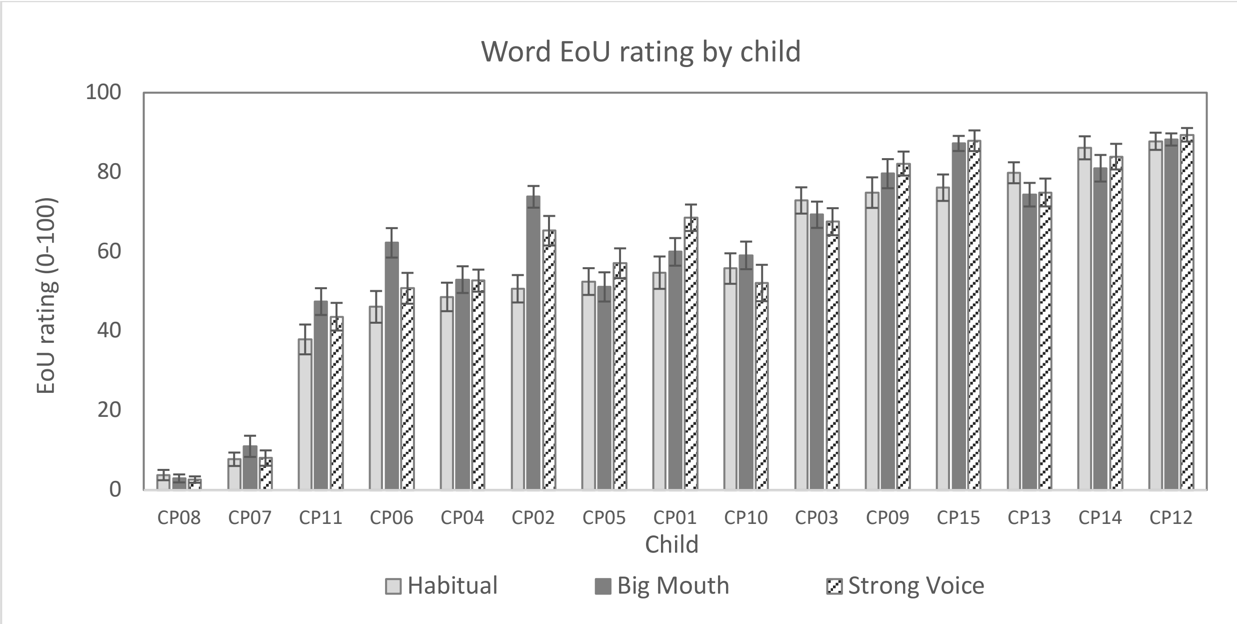
3.2 Intelligibility changes across speaking conditions

3.2.1. Word level

3.2.1.1. Ease of understanding ratings

Figure 1 presents the average group EoU ratings along with individual EoU ratings across the three speaking conditions for the 15 Korean-speaking children with dysarthria. The individual results are presented in order of increasing EoU in the habitual condition. On the scale from 0 ("difficult to understand") to 100 ("easy to understand"), the mean group EoU ratings for the word listening task were 55.69 (SD = 25.51) for habitual condition, 60.01 (SD = 25.07) for the BM condition, and 59.10 (SD = 26.10) for the SV condition. This indicated an increase in listeners' EoU of the children's speech in both cued conditions. Linear mixed effects analysis revealed a significant main effect of speaking condition, $F(2, 1798) = 9.35$, $p < .001$. Post-hoc analyses showed significant increases from habitual to BM (mean difference = 4.32; $t = 2.10$, $p < .001$) and from habitual to SV (mean difference = 3.42; $t = 2.04$, $p = .004$). The difference between BM and SV was not statistically significant (mean difference = 0.90; $t = 0.66$, $p > .50$).

At the individual level, 10 of the 15 children revealed an increase in EoU at the word level with at least one cue. Closer examination indicated that the 10 children who exhibited an increase in EoU in the BM condition showed an average of 15.1% EoU increase (range: 0.5% – 45.7%), and the 10 children with increased EoU in the SV condition showed an average of 12.8% EoU increase (range: 1.9% – 28.8%). Furthermore, 5 children experienced a decrease in EoU with one or both cues, with an average of 8.6% decrease (range: 2.6% – 22.4%) in the BM condition and an average of 10.5% decrease (range: 2.6% – 30.0%) in the SV condition.



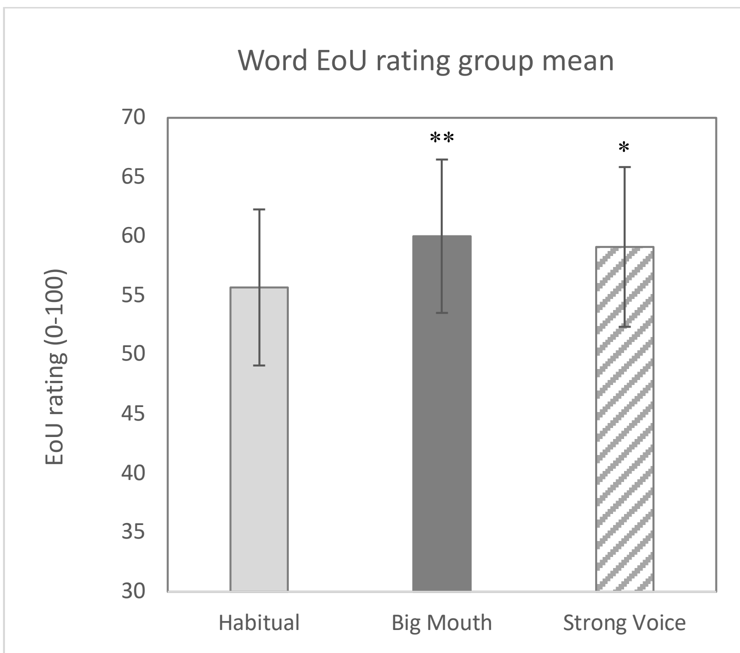
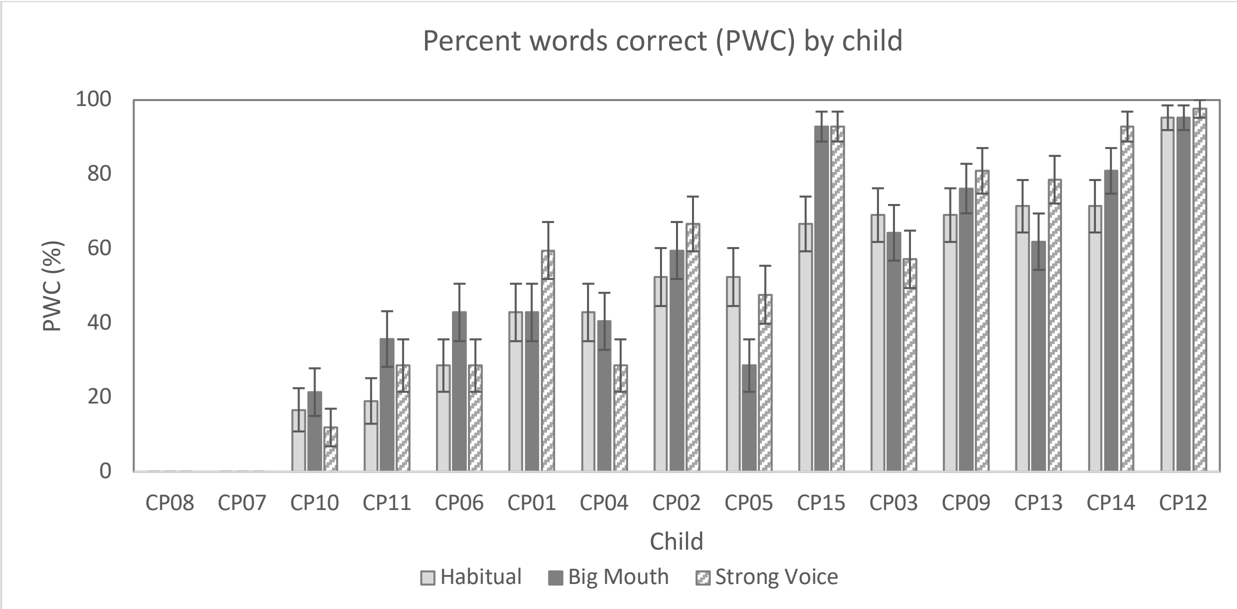


Figure 1: Word-level Ease of Understanding (EoU) ratings for each of the 15 children with dysarthria and the group means across habitual, big mouth, and strong voice conditions. EoU ranged from 0 (difficult to understand) to 100 (easy to understand). Children are listed in order of increasing EoU rating in habitual condition. Standard error bars are included. *$p < .01$, **$p < .001$.

3.2.1.2. Percentage of words correctly transcribed

Word intelligibility was also examined through orthographic transcription (percentage of words correctly transcribed; PWC). The average PWC at the group and individual levels for the three speaking conditions and are shown in Figure 2. The average group PWC was 46.5% (SD = 28.6) in the habitual condition, 49.5% (SD = 30.0) in the BM condition, and 51.4% (SD = 33.7) in the SV condition. Binomial mixed effects analysis revealed that the effect of speaking condition on PWC did not reach statistical significance, $F(2, 1784.1) = 2.70$, $p = 0.067$.

The individual results in Figure 2 are presented in increasing order of PWC in the habitual condition. Out of the 15 children, 10 exhibited an increase in PWC in response to one or both cues, with 7 children demonstrating an average of 34.7% increase (range: 13.3% – 50.0%) in the BM condition, and 8 children with an average of 26.9% increase (range: 2.5% – 50.0%) in the SV condition. In the 5 children who exhibited a decrease in PWC in response to one or both cues, 4 children demonstrated an average of 17.8% decrease (range: 5.6% – 45.5%) in the BM condition, and 4 children showed an average of 22.1% decrease (range: 9.1% – 33.3%) in the SV condition.



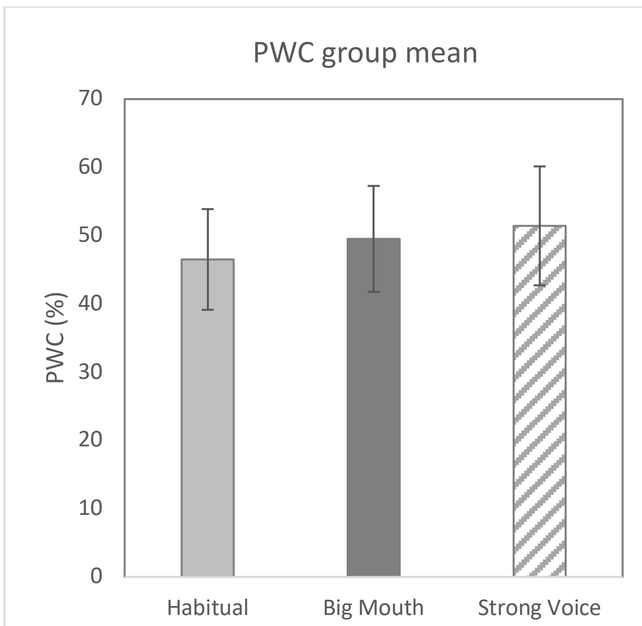
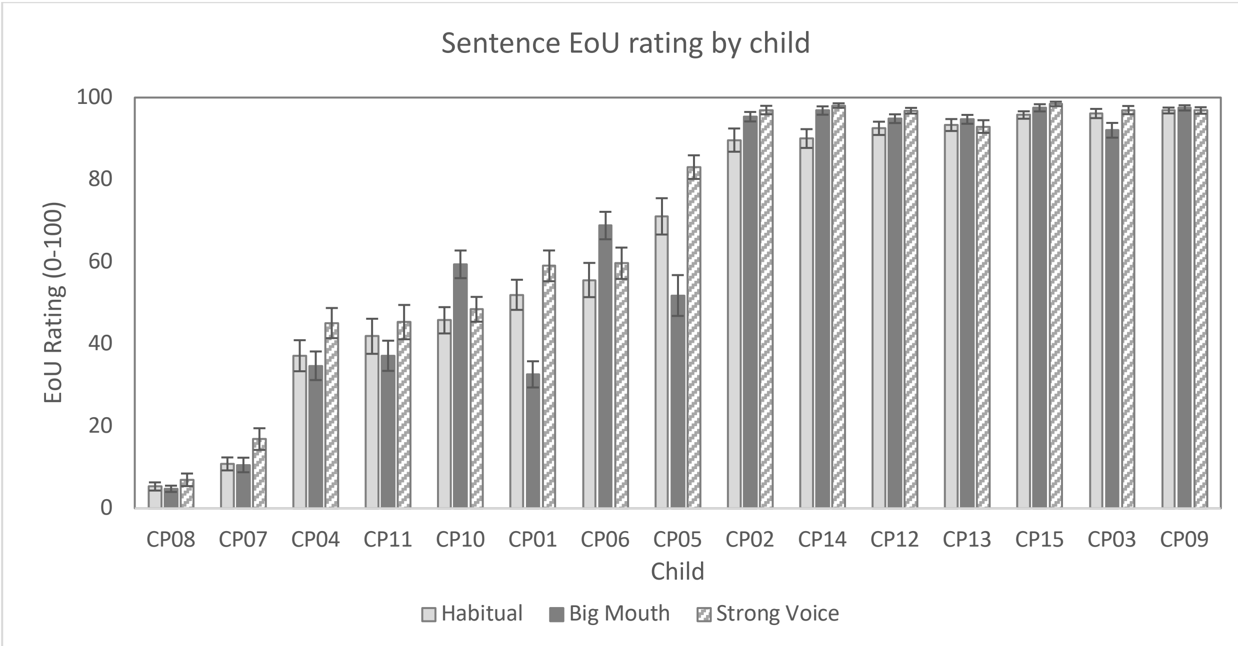


Figure 2: Percentage of words correctly transcribed (PWC) for each of the 15 children with dysarthria and the group means across habitual, big mouth, and strong voice conditions. Children are listed in order of increasing PWC rating in habitual condition. Standard error bars are included.

3.2.2. Sentence level

Figure 3 presents the average sentence EoU of the 15 children with dysarthria across the three speaking conditions. The average group EoU ratings were 64.92 (SD = 31.84) for the habitual condition, 64.57 (SD = 33.92) for the BM condition, and 69.43 (SD = 31.51) for the SV condition. Linear mixed effects analysis revealed a significant main effect of speaking condition, $F(2, 2328) = 19.37$, $p < .001$. Post-hoc analysis revealed a significant increase in sentence EoU in the SV condition (mean difference = 4.51, $t = 5.00$, $p < .001$) but not in the BM condition (mean difference = -0.35, $t = -0.14$, $p > .05$) relative to the habitual condition. Furthermore, sentence EoU in SV condition was significantly greater than in BM (mean difference = 4.86, $t = 1.67$, $p < .001$). This indicated that on average, cueing the children to use a strong voice resulted in positive changes to EoU ratings; however, the preferred condition and degree of change varied across children.

The individual children's data in Figure 3 are presented in increasing order of sentence EoU in the habitual condition. Out of the 15 children, 14 exhibited an increase in EoU in response to at least one of the cues. Further examination revealed that 8 children showed an average of 9.3% increase (range: 0.7% – 29.7%) in the BM condition and 13 children showed an average of 14.2% increase (range: 0.9% – 55.9%) in the SV condition. In addition, 8 children experienced a decrease in EoU with one or both cues, with 7 children demonstrating 14.2% decrease (range: 2.4% – 37.3%) in the BM condition and 1 child demonstrating 0.4% decrease in the SV condition.



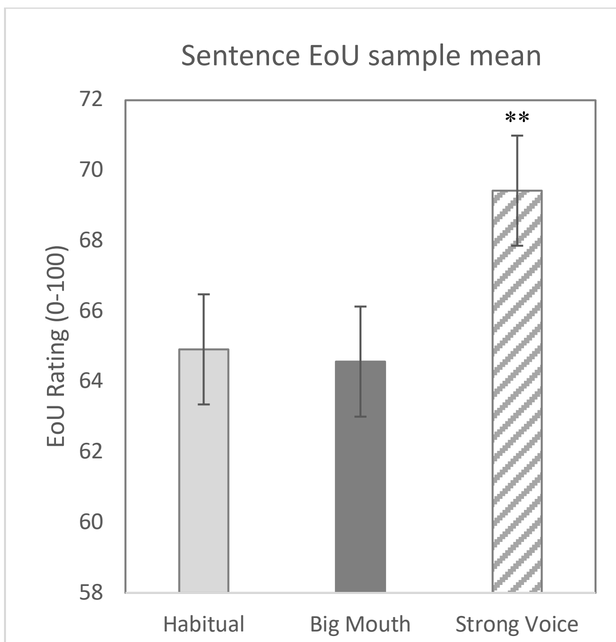


Figure 3. Sentence-level Ease of Understanding (EoU) rating for each of the 15 children with dysarthria and the group means across habitual, big mouth, and strong voice conditions. EoU ranged from 0 (difficult to understand) to 100 (easy to understand). Children are listed in order of increasing EoU rating in habitual condition. Standard error bars are included. **p < .001.

3.3 Relationship between acoustic and intelligibility measures

Pearson product moment correlation analyses were conducted to assess the relationship between acoustic measures (duration, VSA, and SPL) and intelligibility (EoU and PWC). At the word level, no significant correlation was found between word EoU changes and changes in the three acoustic measures of interest (all $p > .10$). Furthermore, no significant correlation was found between changes in PWC and changes in duration or VSA. However, there was a significant strong positive correlation between changes in PWC and changes in SPL in the BM condition, $r(15) = .60$, $p = .019$. In addition, there was a moderate positive correlation between changes in PWC and changes in SPL in the SV condition, $r(15)= .44$, $p = .098$. These findings suggest that as SPL increased, PWC tended to increase in the BM condition and likely in the SV condition.

At the sentence level, there was no significant correlation between changes in EoU and changes in the acoustic measures (all $p > .10$), although a moderate negative correlation was noted between changes in EoU and changes in duration, $r(15) = -.46$, $p = .085$. Furthermore, no significant relationship between intelligibility and acoustics measures was found in the subgroup of children who demonstrated an increase in EoU or PWC (all $p < .10$). Overall, the relationships between the acoustics and intelligibility changes following BM and SV at the group level were variable.

3.4 Subgroup analyses based on dysarthria severity

Subgroup analyses were performed across the children's dysarthria severity categories to determine whether effects of BM and SV cues on acoustic speech measures and intelligibility manifest differently as a function of severity. It has been suggested that children may respond differently to speech modification techniques depending on their dysarthria severity (e.g., Sakash et al., 2020). For the current analysis, the 15 children were divided into three subgroups according to their dysarthria severity as determined by three SLPs. This division was also consistent with other measures of severity (i.e., habitual EoU and PWC[1]). The three severity subgroups were mild (n = 4), moderate (n = 8), and severe (n = 3).

For the mild severity group, linear mixed effects analysis revealed no significant main effect of speaking condition on word EoU ($F(2, 440.3) = 0.53$, $p = .588$). However, there was a significant effect of speaking condition on PWC, $F(2, 438.2) = 7.60$, $p = .001$. Post-hoc pairwise comparisons of PWC revealed significant gains in the SV condition (mean difference = 14.10, $p < .001$). PWC gains in the BM condition did not reach significance in the mild group (mean difference = 6.48, $p = .209$). Furthermore, there was a significant main effect of speaking condition on sentence EoU, $F(2, 608) = 17.8$, $p < .001$. Post-hoc analyses revealed significant sentence EoU gains in both the BM (mean difference = 3.08, $p < .001$) and the SV (mean difference = 3.66, $p < .001$) conditions. The gains in the two cued conditions were not significantly different from each other. Taken together, findings suggest that in children with mild dysarthria, the SV cue may result in a significant increase in word intelligibility (as measured by PWC) as well as sentence intelligibility, but the BM cue may elicit significant intelligibility gains at the sentence level only.

For the moderate severity group, there was a significant main effect of speaking condition on word EoU ($F(2, 1053)= 10.57$, $p < .001$), with gains following both cues relative to the habitual condition (BM mean difference = 6.78, $p < .001$; SV mean difference = 5.25, $p = .002$) and no significant difference between the cues (mean difference = 1.53, $p = .974$). However,

[1] There was a significant positive strong correlation between severity rating and intelligibility in the habitual condition (word EoU: $r(15) = .899$, $p < .001$; PWC: $r(15) = .868$, $p < .001$).

neither cue increased PWC significantly ($F(2, 1058.7) = .25$, $p = .778$). At the sentence level, there was a significant effect of speaking condition on EoU, $F(2, 1263.6) = 13.51$, $p < .001$, with post-hoc pairwise comparisons demonstrating significant gains in the SV condition (mean difference = 5.24, $p = .008$) but not in the BM condition (mean difference = 1.49, $p = 751$). Thus, for children with moderate dysarthria, both BM and SV cues may elicit significant intelligibility gains at the word level (as measured by EoU), but only the SV cue might bring about a significant increase in intelligibility at the sentence level.

For the severe group, there was a significant main effect of speaking condition on word EoU, ($F(2, 345.7) = 3.20$, $p = .043$). Post-hoc analysis revealed a significant increase in word EoU with BM (mean difference = 4.45, $p = .037$) but not with SV (mean difference = 2.14, $p = .666$). Furthermore, the BM and SV cues did not increase PWC significantly in this group ($F(2, 360.5) = 2.17$, $p = .116$). At the sentence level, a significant effect of speaking condition on sentence EoU was observed ($F(2, 438.2) = 4.21$, $p = .015$), with significant gains following SV (mean difference = 3.93, $p = .028$) but not BM (mean difference = .39, $p < .05$). Therefore, for children with severe dysarthria, BM may increase word intelligibility (as measured by EoU), and SV may increase sentence intelligibility. No pattern was evident regarding other possible factors (e.g., age, gender) that may have contributed to the gains in intelligibility.

Chapter 4: Discussion

The primary purpose of this study was to determine if the two potentially intelligibility-enhancing cues, "speak with your big mouth" and "speak with your strong voice," would elicit changes in speech acoustics and intelligibility in Korean-speaking children with dysarthria secondary to CP. Results indicated greater vocal intensity and longer utterance duration in the cued conditions, demonstrating the children's ability to vary their speech styles in response to the two cues. In terms of intelligibility, the big mouth cue yielded significantly greater EoU than in the habitual condition at the word level. However, no significant EoU changes resulted from the big mouth cue at the sentence level. The strong voice cue resulted in significantly greater EoU (than habitual speech) at both the word and sentence levels. Furthermore, there was a trend toward an increase in PWC following both cues, but the gains did not reach statistical significance. Considerable variability in the children's responses to the cues was noted overall. Below we discuss the results, comparing them to those from studies on AE- and French-speaking children with dysarthria, and suggest implications for treatment strategies.

4.1 Acoustic changes in response to speech cues

Based on past research on the effects of the big mouth and strong voice cues (Levy et al., 2017; 2020), it was expected that Korean-speaking children with dysarthria would be able to modify their speech in response to both cues, as evidenced by changes in particular acoustic measures. As hypothesized, utterance duration and vocal SPL increased significantly in response to the cues. An overlap of acoustic changes was also observed in the cued conditions, such as greater word-level SPL in the big mouth condition and greater utterance duration in the strong voice condition. In addition, acoustic VSA was analyzed for evidence of articulatory excursion changes in response to the cues. A trend toward greater VSA was noted in the cued conditions compared to the habitual condition, but the changes were small and not statistically significant. Overall, the children whose habitual VSA was smaller than the group average tended to show an increase in vowel space in the cued conditions. In contrast, those with habitual VSA greater than average showed little to no vowel space expansion when speaking with their big mouth or their strong voice. We speculate that the extent of VSA expansion elicited through the two cues may depend on the child's habitual VSA. Overall, the changes in duration and SPL suggest that the children were on task and able to make acoustic modifications in response to the two speech cues. These findings generally concur with the increased duration and SPL observed in English-speaking and French-speaking children with dysarthria when they were provided with the two cues (Levy et al., 2017; 2020).

4.2 Intelligibility changes in response to speech cues

Along with the changes in the acoustic measures, significant increases in EoU were found in response to both cues. On average, EoU at the word level increased by 8% following the big mouth cue. Following the strong voice cue, the word-level and sentence-level EoU increased by 6% and 7%, respectively. Furthermore, greater intelligibility gains were observed in the subgroup of children whose intelligibility increased in response to the cues. These children's intelligibility increased by approximately 15% and 9% at the word and sentence levels, respectively, in the big mouth condition, and by 13% and 14% at the word and sentence levels in the strong voice condition. Because intelligibility gains above 8% are considered clinically meaningful (Stipancic et al., 2015; Tjaden et al., 2014; Van Nuffelen et al., 2010), cueing big mouth and strong voice holds promise for eliciting meaningful intelligibility changes in Korean-speaking children with dysarthria.

In contrast to the significant EoU gains following the big mouth and the strong voice cues, the gains in PWC in the two cued conditions did not reach significance. The discrepancy between average EoU and PWC at the word level may have been affected by the considerable individual differences in the present study's small sample of children. Additionally, the moderate to strong positive correlations between PWC and SPL suggest that PWC may increase significantly if greater SPL can be elicited by the cues. In the present study, however, the changes may not have been sufficient to yield a statistically significant increase in PWC. While PWC may be considered a relatively objective measure of intelligibility, listener ratings (such as EoU) are also widely used to quantify intelligibility in dysarthria (e.g., Kim et al., 2011; Stipancic et al., 2016; Tjaden et al., 2014; Yunusova et al., 2005). EoU ratings reflect the listeners' judgments of the extent to which the utterances were understood. Thus, the cued conditions may have been highly rated because the listeners preferred them over the children's habitual speech. Further examination with a greater number of children and more detailed information on the listeners' impressions of the children's speech in the different conditions may elucidate the nature and extent of word-level intelligibility changes in response to the two cues.

Furthermore, to investigate whether one cueing strategy was more effective in increasing intelligibility than the other, changes in EoU in the two cued conditions were compared. At the word level, both cues elicited significant increases in EoU over habitual speech. Moreover, the gains in the cued conditions were not significantly different from one another, suggesting that the two cueing strategies were equally effective in increasing EoU at the word level. However, at the sentence level, EoU increased significantly following only the strong voice cue. We speculate that greater SPL, and possibly concomitant acoustic characteristics elicited by the strong voice cue, may have contributed to such sentence-level gains. In contrast, the big mouth cue elicited longer sentence duration, but did not yield other potentially intelligibility-enhancing characteristics such as greater SPL or expansion of the VSA (e.g., Levy et al., 2017; Smiljanić & Bradlow, 2009). Furthermore, the lack of improvement in sentence intelligibility following the big mouth cue may be attributed to a reduction in prosodic contrast and naturalness associated with slow speech rate (Patel et al., 2012; Tjaden et al., 2014). Thus, examining prosody in more detail may provide more thorough explanations for the differences in intelligibility observed between the BM and the SV conditions at the sentence level.

Moreover, analyses were performed to examine whether the changes in intelligibility in the cued conditions varied across the dysarthria severity subgroups (mild, moderate, severe). The strong voice cue elicited an increase in word-level EoU for children with mild and moderate dysarthria, and an increase in sentence-level EoU for all three subgroups. Additionally, the big mouth cue elicited increased word-level EoU for children with moderate and severe dysarthria, and increased sentence-level EoU for children with mild dysarthria. Thus, the degree of EoU improvement and linguistic (word vs. sentence) level may vary as a function of the child's dysarthria severity.

Clinically, our findings suggest that the big mouth and the strong voice cues show promise for improving listeners' ease of understanding of utterances produced by Korean-speaking children with dysarthria. It should be noted, however, that some children benefited more from one cue than the other. For example, a child with loudness variations that ranged from whisper to typical voice benefited more from the strong voice cue. In contrast, a child with great habitual vocal intensity, high mean F0, and rapid speech rate benefited more from the big mouth cue. Thus, clinicians may consider testing stimulability of both cues in order to determine which strategy or strategies best addresses the child's needs.

4.3. Preliminary comparison of acoustic and intelligibility changes across languages

The findings of the present study and of previous cueing studies on children with dysarthria who speak AE (Levy et al., 2017) and French (Levy et al., 2020) may permit comparisons of changes in speech acoustic and intelligibility across the three language groups. Such discussions may begin to reveal language-specific and more language-independent effects of the cues. The children in the three language groups were able to modify their speech in response to the big mouth and the strong voice cues. In all three groups, the big mouth cue yielded longer utterance duration and the strong voice cue yielded greater SPL, relative to the measures in the habitual condition. However, differences across the groups were observed in the spectral measures of vowels. In the French-speaking children, both cues yielded significant increases in the first formant (F1) and the second formant (F2) of /a/, /u/, /e/, and /o/, but no significant formant changes were elicited by either cue in the AE-speaking children. In Korean-speaking children, an increase in VSA, calculated from F1 and F2 of three corner vowels, was observed in both cued conditions, but the gains were not statistically significant. Investigations with a larger number of children and with utterances of various linguistic and prosodic characteristics will help strengthen our understanding of how these cues affect the acoustic characteristics of speech across languages.

Furthermore, commonalities and differences are evident among the cues' effects on intelligibility in children across the three language groups. Intelligibility changes at the word level observed in Korean-speaking children with dysarthria are similar to those reported in the French-speaking children (Levy et al., 2020). For children in both language groups, the two cues elicited increases in word-level EoU, with no significant difference between the effects of the cues. Moreover, PWC did not increase significantly as a function of the cues in Korean and

French speakers. For AE-speaking children (Levy et al., 2017), in contrast, the two cues elicited significant EoU and PWC gains, with greater gains from the big mouth cue than from the strong voice cue. Thus, findings suggest that both cues may improve word EoU in AE-, French-, and Korean-speaking children, but the extent of improvement with the big mouth cue may be somewhat language-specific.

Intelligibility changes at the sentence level resulting from the two cues were different in the Korean-speaking children from those in the AE- (Levy et al., 2017) and in the French-speaking children (Levy et al., 2020). Specifically, only the strong voice cue elicited significant gains in EoU in the Korean-speakers, whereas both cues elicited increased EoU in the AE-speaking children, and neither cue increased EoU in the French-speaking children. Anecdotally, French speakers and Korean speakers reported that the utterances in the big mouth condition sounded unnatural in their respective languages. We speculate that the big mouth strategy may negatively affect prosody by lengthening syllable durations in these syllable-timed languages, rendering the words less natural sounding, thus reducing their intelligibility. In addition, languages with more contrastive vowel pairs in close proximity within the acoustic vowel space, such as AE, may experience greater benefits from vowel space expansion through the big mouth strategy than would languages with fewer vowels, such as Korean. In comparison to English, both Korean and French have fewer front-back and high-low distinctions in close proximity (Yang, 1996), and thus, expansion of the vowel space may have less impact on increasing intelligibility.

Taken together, findings preliminarily suggest that while the big mouth and the strong voice cues may improve intelligibility across different language groups, the extent of the effects of the big mouth cue may be somewhat language-specific. However, conclusions that can be drawn from these comparisons are tentative until larger cross-linguistic studies involving greater numbers of children are conducted.

4.4 Limitations and future directions

There were several limitations to the present study. First, the small number of children included in the analysis presented with a wide age range and varying degrees of dysarthria severity, limiting generalization to other populations. In addition, the relationship between an increase in EoU following the two cues and factors such as age or dysarthria severity could not be determined from this study. Speech produced by a larger number of children with dysarthria, as well as speech of neurotypical children and of children with CP without a dysarthria diagnosis (e.g., Allison & Hustad, 2018), should be examined in the future to better assess how age and dysarthria severity may impact cueing effects. This information could aid in clinical decisions regarding appropriate therapeutic approaches for children with particular characteristics.

Only three acoustic measures (duration, SPL, and AVS) were examined in relation to intelligibility. Although duration and SPL increased significantly following the cues, no significant correlation, other than that between SPL and PWC, was found between the acoustic and intelligibility measures in the present analysis. Further acoustic factors, such as mean F0 (Lee et al., 2014; Patel et al., 2012; Jeong & Sim, 2020), F2 slope (Lee et al., 2014; Allison & Hustad, 2018; Lee et al., 2016), F2 difference (Levy et al., 2021), as well as consonantal measures such as fricative duration (Ansel & Kent, 1992; Kim & Kim, 2013; Hernandez et al., 2019) and voice onset time (Jeong et al., 2011; Kim & Choi, 2017) may shed light on the nature of the changes that improve intelligibility in response to the cues.

Additionally, listeners heard various speakers producing the same sentences during the sentence listening task, which could have affected their judgment. While the stimuli and the children's speech samples were played in a random order to the listeners to minimize such effects, further analyses that include a greater variety of sentences would permit a more thorough examination of sentence-level intelligibility.

Lastly, the results of this study reflect immediate changes in response to cueing, but they do not necessarily predict long-term effects of the big mouth and the strong voice strategies. Such changes in speech may be observed through studies of speech treatment, such as SIT, which has shown intelligibility improvements in AE-speaking (Levy et al., 2021) and French-speaking (Moya-Galé et al., 2021) children, when the big mouth and strong voice cues are combined in a speech treatment program. Similarly, to explore the long-term intelligibility benefits of the cues in Korean-speaking children with dysarthria, treatment studies are needed to test speech changes and maintenance thereof in this population following weeks of training (e.g., Levy et al., 2021; Moya-Galé et al., 2021; Fox & Boliek, 2012).

Conclusion

Our findings provide preliminary support for the use of two cueing strategies, the Korean translation of "speak with your big mouth" and "speak with your strong voice," to improve intelligibility of Korean-speaking children with dysarthria secondary to CP. Generally, the strong voice strategy may be beneficial for Korean-speaking children regardless of dysarthria severity, although a combination of the two strategies may be optimal for some children. Thus, stimulability to the cues should be examined for each child in order to assess which cueing strategy, or combination of strategies, might produce the greatest intelligibility gains.

These findings contribute to the limited knowledge base for SLPs working with Korean speaking children with dysarthria in the US and globally. Studies of responses to speech cues in further languages will inform questions regarding how language-specific and more universal responses to the speech cues relate to dysarthria treatment efficacy across languages. Ultimately, such information, if implemented clinically, may help children with dysarthria from a wider range of language backgrounds to speak with greater intelligibility.

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Appendix A

List of 21 Korean Contrastive Monosyllabic Words

달	탈	딸	땀	살	쌀	산
/tal/	/tʰal/	/t͈al/	/t͈am/	/sal/	/s͈al/	/san/
굴	꿀	쿨	공	콩	방	병
/k̲u̲l/	/k͈ul/	/kʰul/	/koŋ/	/kʰoŋ/	/paŋ/	/pjʌŋ/
짐	침	찜	잠	발	팔	빨
/tɕim/	/ tɕʰim/	/t͈ɕim/	/tɕam/	/pal/	/pʰal/	/p͈al/

Note. Each word was embedded in a carrier phrase, "“*Dashi* CVC *haeyo”* [Say CVC again].

Appendix B

Intelligibility Assessment Instruction for Listeners

Task 1: Word level Ease-of-Understanding rating and orthographic transcription

이 테스트가 시작되면 “다시 ( ) 해요" 라는 문장이 나옵니다. 잘 듣고 ( )에 들어가는 단어를 흰 창에 쓰세요.
말을 하는 아이가 긴 문장 산출이 어려웠을 경우, 짧게 “( ) 해요"나, 문장이 아닌 단어 “( )” 만 하기도 합니다.
흰 창에는 괄호 ( )에 들어가는 단어만 적으세요.
예시: “다시 곧 해요"라는 문장을 듣고서 흰 창에 “곧"이란 단어만 적습니다.
듣게 될 단어들은 모두 한 음절의 단어입니다.

만약 아이의 말을 알아듣기 힘들었을 경우, 추측해서 비슷한 단어를 적어주세요.
단어를 흰 창에 적은 후, 밑에 있는 막대 바 (bar)을 사용하여 아이가 말한 단어를 알아듣는게 얼마나
쉬웠는지/어려웠는지 표기합니다.

처음 들을 6 개의 단어는 연습용입니다.

아이의 말을 주의 깊게 들어주세요. 다시 듣기는 불가능합니다.
테스트가 진행되는 동안 스피커로 가까이 이동하지 말아주세요.

(English translation)
You will hear a child saying, “They say (TARGET WORD) again.”
Please listen to the child’s speech. Type exactly what word you thought the child said. (These are all real words.) Sometimes, you might hear only “(TARGET WORD) again”, or just “(TARGET WORD)”. This is because some children had difficulty saying the full sentence. Please only write down the TARGET WORD.

If you don’t understand what the child said, please make your best guess and write down what you think you heard.

Next please indicate how easy the word was to understand by placing a mark along the scale from “difficult” to “easy”.

The first 6 phrases you will hear are only for practice. During the actual task, the children you will hear may be more difficult to understand than during the practice.

Note:
Please listen carefully, as we cannot replay the sound file.
Please do not lean forward toward the speakers.

Task 2: Sentence level Ease-of-Understanding rating

테스트가 시작되면 아이들이 산출한 여러 문장이 나옵니다.
잘 듣고 밑에 있는 막대 바 (bar)을 사용하여 아이가 말한 문장을 알아듣는게 얼마나 쉬웠는지/어려웠는지 표기합니다.

아이의 말을 주의 깊게 들어주세요. 다시 듣기는 불가능합니다.
테스트가 진행되는 동안 스피커로 가까이 이동하지 말아주세요.

(English translation)
You will hear a child saying several sentences. Please listen to the child's speech. Indicate how easy the sentence was to understand by placing a mark along the scale from "difficult" to "easy".

Note:
Please listen carefully, as we cannot replay the sound file.
Please do not lean forward toward the speakers.