Voice and Speech Outcomes Following Intensive Voice and Motor Speech Treatment Delivered Sequentially to Children with Motor Speech Disorders Secondary to Cerebral Palsy

by

Nancy Eason

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Department of Communication Sciences and Disorders
University of Alberta

Abstract

Purpose: The purpose of this retrospective study was to examine the treatment outcomes in children with a mixed diagnoses of dysarthria and childhood apraxia of speech (CAS), secondary to Cerebral Palsy (CP) after the completion of LSVT®LOUD followed by a six-week motor speech treatment. **Method:** A single case research design was used to examine the speech outcomes in four children (12 to 16 years of age; 3 females) who completed LSVT LOUD, consisting of 16 hours of individual 1-hour treatment sessions within a 4-week time period. After a 12-week maintenance program, these same children underwent intensive motor speech treatment for an additional six-week period, consisting of 18 hours of therapy comprised of 30-minute individual sessions followed by 1-hour group sessions, twice per week. Perceptual, intelligibility, and speech acoustic variables were collected and assessed at four different time points: pre- and post-treatment for both therapy types. In addition, nasalance scores were collected at pre- and post- motor speech treatment. **Results:** Three of four participants displayed increased dB SPL at post-LSVT LOUD and 12-weeks follow-up compared to pre-treatment measures. A visual trend illustrated increased percent intelligibility post-LSVT LOUD for all four participants with significantly higher ratings at 12-weeks follow-up. Additional gains in dB SPL, intelligibility, diadokokinetic performance, and vowel space were observed following motor speech treatment. **Conclusion:** Results indicated positive therapeutic outcomes following both treatment approaches and provides some initial information on the use of sequential treatment approaches in children with motor speech disorders secondary to CP.

Key Words: Cerebral Palsy, Dysarthria, Childhood Apraxia of Speech, Speech and Voice Treatment, Intelligibility, Speech Acoustics

Preface

This thesis is an original work by Nancy Eason. The research project, of which this thesis is a part, received research ethics approval from the University of Alberta Research Ethics Board, Project Name: *Neural correlates of intensive voice treatment effects on children with cerebral palsy*, Pro00038076, 20 March, 2013.

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Figure 17. Summary Data for DDKs (MRRmono). Monosyllabic repetition rates in syllables per second across all time points and participants, depicted in different colors *(*lsvtf1 = blue; lsvtf3 = red; lsvtf7 = green; lsvtm9 = purple). Where dotted line = separation between LSVT LOUD and motor speech treatment; Pre = pre-LSVT LOUD; Post = post-LSVT LOUD; FUP = follow-up LSVT LOUD/pre motor speech; PostM = post-motor speech; asterisked value indicates a statistically significant change; superscript t value indicates a trend; − indicates no change.

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Voice and Speech Outcomes Following Intensive Voice and Motor Speech Treatment Delivered Sequentially to Children with Motor Speech Disorders Secondary to Cerebral Palsy

Cerebral Palsy (CP) is an early onset movement disorder, with a prevalence of 2.11 out of 1000 live births (Oskoui, Coutinho, Dykeman, Jetté, & Pringsheim, 2013). Cerebral palsy describes a group of individuals who had an *in utero* stroke or other brain damage (i.e., asphyxia) at or near the time of birth. Early brain damage associated with CP impacts the developing nervous system resulting in a diverse range of neuromuscular disorders, including motor speech disorders such as dysarthria and apraxia of speech.

Dysarthria

Dysarthria arises from impaired control of the subsystems involved in speech production (Pennington, Roelant, Thompson, Robson, Steen, & Miller, 2013). Approximately 50% of children with CP have co-occurring communication disorders (Pennington, Miller, Robson, & Steen, 2009), with approximately 35% of these cases diagnosed as some type of dysarthria (Pennington et al., 2013). Because dysarthria is a motor interruption of speech involving one or more of the speech subsystems or the coordination among them, children who present with dysarthria often have reduced intelligibility. Characteristics of voice and speech in this population include: reduced or variable vocal loudness, mono-pitched, breathy or strained-strangled voice quality, hypernasality and poor articulation (Boliek & Fox, 2014; Pennington et al., 2009; Solomon & Charron, 1998; Workinger & Kent, 1991). Specifically, individuals with flaccid type dysarthria typically demonstrate vocal fold or laryngeal-respiratory weakness. This dysarthria type is characterized by continuous breathiness, diplophonia, audible inspiration, hypernasality, and short phrases (Duffy, 2013). Spastic type dysarthria is distinguished by slow rate, slow and regular AMRs, hypernasality, and harsh and/or strained voice quality (Duffy, 2013). Additionally, ataxic dysarthria is described by irregular articulatory breakdowns during connected speech, irregular AMRs, and dysprosody (Duffy, 2013). Although it is possible to present with a single dysarthria type the neurological damage, dysarthria is often not bound to a single unit of the motor system resulting in a combination of two or more dysarthria types, labeled as a mixed dysarthria (Duffy, 2013). In general, children with dysarthria have been found to have slower speaking rates, lower intelligibility ratings (Chen, Ni, Kuo & Hsu, 2012; Hodge & Gotzke, 2014), shorter phonation durations, and slower monosyllabic repetition rates compared to typically developing children (Rvachew, Hodge & Ohberg, 2005). Additionally, children with CP and dysarthria exhibit variable vowel formant values and an overall smaller vowel space compared to typical speakers likely contributing to lower intelligibility scores (Chen et al., 2012). These children also display persistent sound substitutions, omissions and distortions (Workinger & Kent, 1991), and have alveolar pressures, lung volumes, airflows, and chest wall shapes that deviate from that of typically developing children (Solomon & Charron 1998).

Treatment Approaches for Dysarthria

Pennington and colleagues (2009) suggest that a multi-system treatment approach, targeting respiration, phonation, resonance, and articulation, is recommended for this population. However, because problems with articulatory precision are often a result of the respiratory, phonatory and resonance subsystems, treatment of articulation is advised only after the management of these other subsystems has been accomplished (Pennington et al., 2009). Pennington and colleagues (2009; 2013) found that treatment focusing on management of respiration, phonatory effort, and speech rate, resulted in increased intelligibility of both single words and connected speech in both older and younger children with CP and dysarthria. Fox and Boliek (2012) provide evidence that Lee Silverman Voice Treatment (LSVT®LOUD) can help improve vocal functioning in children with CP and dysarthria. LSVT LOUD targets vocal loudness with the goal of generalizing speech gains to functional communication (Fox, Ramig, Ciucci, Sapir, McFarland, & Farley, 2006). Fox and Boliek (2012) found that listeners preferred all participants' speech production samples collected post-LSVT LOUD over samples collected pre-treatment. Each treated child also improved on at least one of the acoustic variables and three-quarters of the children demonstrated statistically significant improvements on F_0 range post-treatment. Furthermore, Levy, Ramig, and Camarata (2013) compared the effects of traditional treatment to the effects of LSVT LOUD treatment on three children who presented with dysarthria secondary to CP. Both treatment methods resulted in increased speech function including articulatory proficiency and intelligibility. LSVT LOUD also resulted in increased vocal sound pressure level (SPL) (Levy et al., 2013).

Some clinicians question the use of LSVT LOUD with those having spastic-type dysarthria involving hyper-functional voice use. However, Smith, Ramig, Dromey, Perez & Samandari (1995) and Countryman, Hicks, Ramig, Smith (1997) found that individuals with Parkinson's disease demonstrated increased vocal loudness following intensive voice treatment. These individuals displayed improved laryngeal closure and decreased glottal incompetence without increases in supraglottal hyperfuntion (Smith et al., 1995), and improved overall voice quality (Countryman et al., 1997) following treatment.

To date there are no studies that have looked at speech acoustics in terms of vowel space pre- and post-treatment in this population. However, individuals with dysarthria secondary to

Parkinson's disease demonstrated a lowered F2 for /u/ and heightened F2 for /i/ following LSVT LOUD, resulting in frequency values that shifted in the direction of normative values. The changes in F2 values suggested an increase in range of tongue movement post treatment, specifically in the front to back direction (Sapir, Spielman, Ramig, Story, & Fox, 2007).

Childhood Apraxia of Speech

Childhood Apraxia of Speech (CAS) is a neurological disorder, with an estimated prevalence of 0.125%, equating to approximately 1-2 children out of 1000 births (Shriberg, Aram, & Kwiatkowski, 1997). Children with CP frequently have secondary diagnoses of CAS (Iuzzini & Forrest, 2010), which often coexists with dysarthria. CAS results in decreased intelligibility due to variability in duration, displacement, velocity and movement stability of the muscles used during speech production (Grigos & Kolenda, 2009). Children with CAS demonstrate inconsistent errors in speech sounds, untimely transitions between sounds and syllables, and inappropriate use of prosody (*American Speech-Language-Hearing Association*, 2007). Further characteristics of CAS consist of groping or silent posturing (the positioning of the articulators with or without sound production), as well as irregular vowel and co-articulation errors (Terband, Maassen, Guenther, & Brumberg, 2009). Children with CAS produce slow and variable scores on alternating motion rate (AMR) and sequential motion rate (SMR) tasks, and are often unable to produce a correct tri-syllabic sequence (i.e., /pɑtɑkɑ/) (Rvachew et al., 2005; Terband et al., 2009). Although differences in consonant duration in children with disordered speech have not yet been investigated, typically developing children produce vowels of longer duration than that of initial consonants. However, compared to adults, children produce initial middle and final consonants with longer durations (Kim & Stoel-Gammon, 2010). Adult speakers with apraxia of speech have been found to have longer and more variable consonant and vowel durations compared to adults with normal speech (Seddoh, Robin, Sim, Hageman, Moon & Folkins, 1996). Because this cohort of adults with apraxia display similar speech patterns as children with CAS, this population may serve as a better comparison group for children with CAS than their typically developing peers.

Motor programming errors observed in children diagnosed with CAS also may be responsible for nasality inconsistencies, characterized by disruptions in co-articulatory transitions of the velum (Sealey & Giddens, 2010). The velopharyngeal port (VP) opening for the phoneme /p/ in “hamper” in children with CAS was significantly larger compared to children with typically developing speech. There is a broad range for what is considered a normal VP opening; therefore, although the VP opening in children with CAS was at the upper limit of these normative values, the results were still within the acceptable range. Additionally, children with CAS appear to delay impounding intra-oral pressure for production of /p/ in ‘hamper’ thus, requiring more time to reach peak intraoral pressure following the termination of nasal airflow for production of /m/. In the same study, the children with CAS also experienced a larger time delay for closing the velum compared to typically developing age-matched peers (Sealey & Giddens, 2010).

Treatment Approaches for CAS

Research involving the voice and speech treatment for CAS is limited because both the definition and diagnostic criteria for the disorder are controversial (Iuzzini & Forrest, 2010). Differentially diagnosing CAS is challenging due to ambiguity in the criteria used to make a diagnosis of CAS over other speech acquisition disorders (Forrest, 2003). Current research for treatment of CAS can be subdivided into four treatment methods: articulatory, prosodic, tactile/gestural and augmentative (Yorkston, Beukelman, Strand, & Hakel, 2010). Pairing a stimulability training protocol (STP) to increase the child's amount of stimulable sounds with a modified core vocabulary treatment (mCVT) to increase the child's consistency of speech productions yielded greater speech improvements for children with CAS than either treatment on its own (Iuzzini & Forrest, 2010). Similarly, combining melodic intonation therapy (MIT), to target the sequencing of words using prosodic speech elements and touch-cue method (TCM), to target sequencing of speech sounds using facial touch cues successfully increased accuracy of speech production in a child with CAS (Martikainen & Korpilahti, 2011). Furthermore, prompts for reconstructing oral muscular phonetic targets (PROMPT) training that focused on improving jaw movement for the production of speech targets resulted in decreased movement duration and errors, and increased jaw velocity (Grigos & Kolenda, 2010). Greater motor speech gains have been observed when tactile-kinesthetic-proprioceptive (TKP) cues were incorporated into treatment including improvements in intelligibility, focal oromotor control and articulatory sequencing, with additional improvements in social participation (Dale & Hayden, 2013). Additionally, multimodal AAC intervention has been found to provide children with CAS more opportunities to have successful communication and also allowed the children to be more flexible in initiating, participating in and repairing communication breakdowns (Cumely & Swanson, 1999). Taken together, these treatment studies suggest that combining treatment targets may result in greater speech gains compared to outcomes following a single treatment method (Dale & Hayden, 2013; Iuzzini & Forrest, 2010; Martikainen & Korpilahti, 2011).

Recently, clinicians at the Glenrose Rehabilitation Hospital (GRH) implemented a motor speech treatment pilot program that involved five children with mixed diagnoses of dysarthria and CAS. The program was comprised of two modules, one for individual treatment and the other for group treatment. When combined, the two modules targeted articulation through multiple practice opportunities with the goal of building syllable shapes, increasing length of utterance, and targeting speech sounds in context. Results from this initial study showed improved production of multisyllabic words and overall intelligibility (Alton & de Castro, 2012).

Treatment Study Designs

The present study is classified as *Phase I* research, as described in a five-phase model of clinical-outcome research used to structure forms of clinical research throughout audiology and speech language pathology (Robey & Shultz, 1998). Robey and Shultz (1998) introduced this multiphase approach to establishing treatment efficacy and effectiveness. In this context, *Phase I* research is used to introduce human subjects to a new treatment or treatment approach. This type of research typically involves a small sample and typically does not include a control group. Phase I research is used to: *a)* detect potential treatment effects, *b)* determine whether the treatment is safe and, *c)* formulate new research hypotheses for future testing (Robey & Shultz, 1998).

After a series of Phase I studies, *Phase II* research is initiated in order to refine research hypotheses and advance our understanding about how and why a treatment works and for whom. Phase II studies involve a specific population of subjects sampled from the target population only. The focus of Phase II research is to: *a)* create and standardize protocol and methods, *b)* validate measurement tools, *c)* explore factors impacting activity and, *d)* optimize dose. This type of research is a prerequisite to *Phase III* efficacy testing.

Phase III studies test the efficacy of a treatment. This type of research involves testing hypotheses with large samples and a control group. *Phase III* research often leads to the discovery of unexpected applications and benefits of a treatment (Robey & Shultz, 1998). Once initial efficacy is established, *Phase IV* research extends efficacy testing to specified subpopulations, and initiates effectiveness testing. This type of research involves large samples of a target population who reside within a specific geographical area or service delivery model. Participants belonging to the control group may also be receiving treatment that differs from that of the experimental treatment (Robey & Shultz, 1998).

Phase V research aims to advance effectiveness testing. Control samples are not required in this phase, as efficacy and effectiveness have already been established. This type of research investigates post-marketing effectiveness by contrasting outcomes observed in routine compared to optimal service delivery conditions. From here, the focus of *Phase V* research evaluates cost-effectiveness in order to contrast the functional outcomes of a treatment compared to the costs of actually providing the treatment. Finally, *Phase V* research also involves analyzing cost-benefit by contrasting the cost of a treatment to an assigned financial value given to the effects of that treatment (Robey & Shultz, 1998). The present study is characterized as a *Phase I* treatment that was designed in the theoretical context of activity-dependent neuroplasticity.

Activity-Dependent Neuroplasticity

Neuroplasticity refers to the capacity of the central nervous system (CNS) to transform or adjust to changes in environment, behavior, or health condition (Ludlow, Hoit, Kent, Ramig, Shrivastav, Strand, Yorkston, & Sapienza, 2008) and can be induced with extended training (Kleim & Jones, 2008). Kleim and Jones (2008) described a list of activity-dependent principles of neuroplasticity including training specificity, intensity, and adequate task repetitions that help drive structural and neurobiological brain alterations. Through their work with children who have CP, Schertz and Gordon (2008) expanded the elements of activity-dependent neuroplasticity to include intensive repetitions, increased complexity, reinforcement, and inclusion of salient functional goals. In order to induce neural change, treatment must target specific skills that are used functionally on a daily basis such as muscle movements required for respiration and articulation during speaking. Moreover, treatment should include opportunities for extensive and prolonged practice that, in time, will induce changes in neural substrates (Ludlow et al., 2008). The two speech treatment protocols employed in the present study consisted of specific neuroplasticity-principled features as just described.

LSVT LOUD Target. LSVT LOUD is an intensive protocol that targets vocal loudness to build a combined respiratory and phonatory base for speech production (Fox & Boliek, 2012). The high intensity delivery and neural plasticity promoting principles of LSVT LOUD make it an effective training approach for vocal loudness, resulting in improvements across all areas of the speech production mechanism (Fox et al., 2006). Since children with CP and a mixed diagnoses of dysarthria and CAS often display disordered voice and speech characteristics mentioned earlier, targeting vocal loudness is important for this population (Fox & Boliek, 2012; Pennington et al., 2009).

LSVT LOUD Mode. The mode of delivery of LSVT LOUD is 16 hours of individual 1-hour treatment sessions over a 4-week time period. Structured homework and carryover exercises also are assigned during the same period. In the present study, a 12-week maintenance program was scheduled following the 4-weeks of intensive voice therapy providing continued structured practice of skills achieved during LSVT LOUD. Activity-dependent neuroplasticity is reinforced through the specificity of vocal training applied in this treatment approach along with the other principles as presented in Kleim and Jones (2008) and Schertz and Gordon (2008).

Motor Speech Treatment Target. Children with CAS often display groping behaviors and inconsistent speech errors involving vowels, sound sequencing, imitation, and prosody (Grigos & Koolenda, 2010) therefore, it is recommended that articulation be targeted in addition to respiration and phonation. The trained target of motor speech treatment is articulation and speech motor sequencing.

Motor Speech Treatment Mode. The mode of delivery of motor speech treatment is 18 hours of therapy that is broken into 30-minute individual sessions and 1-hour group sessions, twice a week, over a six-week period. Like LSVT LOUD, this motor speech treatment protocol involves extensive and prolonged practice, thus enhancing activity-dependent neuroplasticity (Ludlow et al., 2008). However, the motor speech treatment included multiple treatment targets and fewer repetitions of those targets in comparison to LSVT LOUD.

Purpose

The purpose of the present *Phase I* study was to examine the outcomes of a sequential treatment approach involving LSVT LOUD followed by a motor speech treatment targeting articulation and speech motor sequencing (Alton & de Castro, 2012) in children with mixed diagnoses of dysarthria (spastic-flaccid and ataxic-spastic) and CAS secondary to CP. Based on previous treatment literature specific to this population, it was predicted that by sequentially combining LSVT LOUD followed by a motor speech treatment module, children with a mixed diagnoses of dysarthria and CAS would exhibit additional speech gains than improvements made with LSVT LOUD alone. Specifically, it was predicted that during the production of untrained phrases, vocal loudness (dB SPL) would increase and stabilize following LSVT LOUD. It also was predicted that unfamiliar listeners (speech-language pathologists) would prefer voice samples post-LSVT LOUD compared to pre-treatment samples. Positive changes in overall intelligibility following LSVT LOUD were also predicted. Moreover, it was expected that gains made during LSVT LOUD would be maintained following the 12-week practice period. Following motor speech treatment, it was predicted that increases in intelligibility and listener preference for post-treatment speech on the feature of *articulatory precision* would be observed. In addition, it was predicted that vowel formant space would increase and nasalance would approximate that of typically developing children. Moreover, it was predicted that following motor speech treatment both phrase and sentence speaking rates, along with diadochokinetic (DDK) rates, would increase. Finally, it was hypothesized that children would have smaller consonant proportion durations following motor speech treatment compared to measurements taken from pre-motor speech treatment samples.

Method

Participants

Pre- and post-treatment behavioral data were collected from four participants (12-16 yrs; 3 females). Diagnostic criteria included CP, dysarthria, and CAS. At the time of data collection, three of the four children had a diagnosis of mixed spastic-flaccid dysarthria, and the fourth child had a diagnosis of mixed ataxic-spastic dysarthria. All children were diagnosed with CAS. The Gross Motor Function Classification System – Expanded and Revised (GMFCS-E&R) (Palisano, Rosenbaum, Bartlett, & Livingston, 2007) for CP was used to determine each participant's level of self-initiated movement, with emphasis on sitting, transfers, and mobility. Complete descriptions of the four children along with their individual treatment targets are provided in Table 1.

Table 1. *Participant Descriptions and Treatment Targets*

Participant #	Sex	Age	Speech Diagnosis	GMFCS	Cognitive Level
lsvtf1	F	13	Mixed spastic-flaccid dysarthria and mild CAS Loudness modulation was LSVT target /θ/and /ɡ/ were motor speech targets	III	Above Average
lsvtf3	F	12	Mixed spastic-flaccid dysarthria and mild CAS Loudness modulation was LSVT target /ʃ/, /k/, /ɡ/, and /ŋ/ were motor speech targets	II	Average
lsvtf7	F	16	Mixed spastic-flaccid dysarthria and severe CAS Increasing vocal loudness was the LSVT target /ɛ/, /p/, /b/, functional phrases, and communication repair strategies were motor speech targets	III	Average
lsvtm9	M	13	Mixed ataxic-spastic dysarthria and mild CAS Increasing vocal loudness was the LSVT target Bilabial-velar, alveolar-velar and alveolar-alveolar sound patterns, and /t͡ʃ/ were motor speech targets	IV	Average

Note. F = female, M = male, CAS = childhood apraxia of speech

Design

A single case research design was used in this study to examine the speech outcomes following two, sequentially delivered voice and speech treatment protocols. Each child took part in LSVT LOUD followed by a 12-week maintenance program. Subsequently, these same children participated in an intensive motor speech treatment for an additional six-week period. Treatment schedules for LSVT LOUD and the motor speech treatment are shown in Tables 2 and 3, respectively.

Table 2. *LSVT LOUD Treatment Schedule and Repetition Dose*

Target	Treatment Sessions	Homework on treatment days (4 days/week)	Treatment on non-treated days (3 days/week)	Total Minimum Repetitions in one month	12 Week Maintenance Schedule
Long Ah	15 repetitions per day X 16 days = 240	6 repetitions per day X 16 days = 96	12 repetitions per day X 14 days = 168	504	6 repetitions per day X 84 days = 504
High Ah	15 repetitions per day X 16 days = 240	6 repetitions per day X 16 days = 96	12 repetitions per day X 14 days = 168	504	6 repetitions per day X 84 days = 504
Low Ah	15 repetitions per day X 16 days = 240	6 repetitions per day X 16 days = 96	12 per day X 14 days = 168	504	6 repetitions per day X 84 days = 504
Functional Phrases	10 phrases repeated 5 times per day X 16 days = 800	10 phrases, repeated 2 times per day X 16 days = 320	10 phrases, repeated 4 times per day X 14 days = 560	1680	10 phrases repeated 2 times per day X 84 days = 1680
Structured Reading	Week 1: 20 min X 4 days = 80 min Week 2: 20 min X 4 days = 80 min Week 3: 15	5 min per day X 16 days = 80 min	10 min per day X 14 days = 140 min	440 minutes structured reading/verbal practice with target voice	5 min per day X 84 days = 420 min

	min X 4 days = 40 min Week 4: 5 min X 4 days = 20 min Total= 220 min			
Conversational Speech	Week 1: 5 min X 4 days = 20 min Week 2: 5 min X 4 days = 20 min Week 3: 10 min X 4 days = 60 min Week 4: 20 min X 4 days = 80 min Total= 180 min	5 min per day X 16 days = 80 min	10 min per day X 14 days = 140 min	440 minutes structured conversation with focus on target voice

Note. All tasks increase in complexity and difficulty across the four weeks of treatment.

Table 3. *Motor Speech Treatment Schedule and Repetition Dose*

Target	Repetitions/# of Sessions
lsvtf1	
/θ/ at word level to 80% accuracy	50/4
/ɡ/ at word level (CV and VC syllables) to 80% accuracy	100/2
lsvtf3	
/ʃ/ at beginning of words 80% of the time	43/8
Velars in all word positions at sentence level 80% of the time	40/8
lsvtf7	

/ɛ/ as in 'bed' (CV and VC syllables) 80% of the time	41/12
Voiced/voiceless contrasts for /p/ and /b/ at the word level 80% of the time	23/5
Functional phrases with 80% intelligibility	20/12
Communication repair strategies to repair 80% of communication breakdowns	10/4
lsvtm9	
Bilabial-velar sound patterns (word and sentence level)	45/6
Bilabial-velar target words at spontaneous sentence level to 100% accuracy	24/12
Alveolar-velar sound patterns up to 3 syllables at word level to 100% accuracy in structured activities	48/6
Alveolar-velar target words at spontaneous sentence level to 100% accuracy	24/12
Alveolar-alveolar sound patterns up to 3 syllables at word level to 100% accuracy in structured activities	48/3
/t͡ʃ/ in isolation	24/2

Note. Repetitions/# of Sessions provide some indication of intensity

Procedures

Figure 1 shows the testing and treatment schedule used in the present study. Baseline testing was completed just prior to LSVT LOUD. Immediately following treatment children were tested again. Children went through a 12-week maintenance program (Table 2) during which time they continued to practice skills achieved during LSVT LOUD. At the end of 12-week program, children were tested once again. The follow-up testing session was used as the baseline session for the motor speech treatment. Children were tested again following the 6-week motor speech treatment.

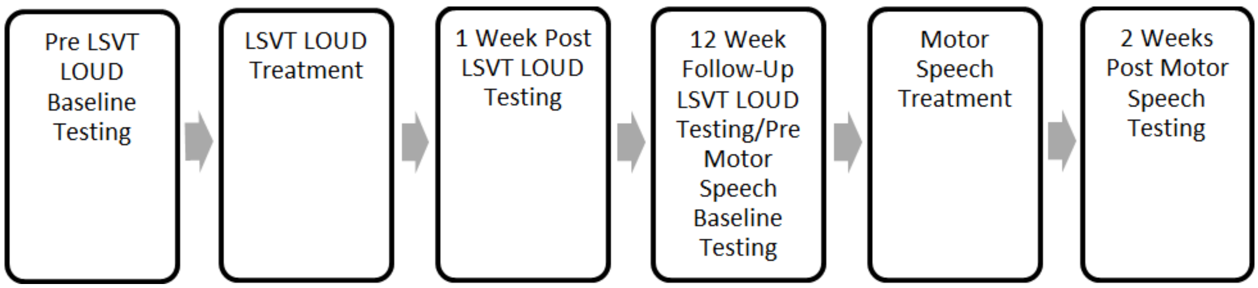


Figure 1. Treatment and data collection sequence.

Data collection procedures were identical across all recording sessions. However, depending on the child, the timing of sessions varied slightly with each taking approximately one hour in duration. Audio signals were captured using a small omni-directional condenser microphone (SHURE MX-185), which was taped to the center of participant's forehead at a distance of 10 cm from the upper-lower lip closure margin of the child's mouth at rest. Audio signals were amplified (M-Audiobuddy Pre-Amplifier) and digitally recorded at a sampling rate of 44.1 kHz on a laptop computer using TF32 Software (Milenkovic, 2001). Calibration of the audio signals involved the presentation of a 440 Hz tone presented at the mouth (KORG Orchestral Tuner, model OT-12) and a sound level meter (ExTech Sound level meter 407764) in line with the forehead-mounted microphone. Sound level in dB SPL was recorded for a 10 second sound sample and used in the calculation of vocal loudness in SPL during off line acoustic analyses. The same experimenters collected all behavioral data across the four testing sessions. These experimenters were not in any way connected to the treatment phase of the study and were trained to be consistent when delivering the experimental protocol.

Children were asked to perform a series of tasks that were not targeted in treatment. These tasks included a variety of word, phrase, and sentences repetitions, DDK tasks, and nasalance testing. More specifically, the first sentence repetition task involved three phrases produced at least three times each: *Buy Bobby a puppy, The potato stew is in the pot,* and *The blue spot is on the key*. Children were asked to imitate a number of words and sentences using the *Test of Children's Speech Plus* (TOCS+) (Hodge, Daniels, & Gotzke, 2012), a software program that randomly selects items from a pool to create a list of single words and a separate list of sentences, each containing a total of 80 words. Selection of sentence length was based on a pre-specified maximum item length chosen to match each child's mean length of utterance (MLU). Additionally, a Nasometer II 6400 (Kay Elemetrics Corporation) was used to collect nasalence scores for each participant pre- and post-motor speech treatment. Due to the retrospective nature of this study, the nasalance component was only added when the study was extended to include a motor speech component of intervention. The nasometer head-set was adjusted to fit snugly on each child's head, positioning the plate perpendicular to the face and between the nose and mouth for appropriate nasal and oral microphone placement. Each child was required to read three speech samples that varied in phonetic content, including the *Zoo Passage*, which does not contain any nasals, the *Rainbow Passage,* which contains nasals and non-nasals, as well as a number of nasal sentences. Two certified speech language pathologists (SLPs) who implemented the motor speech treatment at the Glenrose Rehabilitation Hospital collected supplementary behavioural information.

Intelligibility, perceptual (listener judgment of voice, speech, and resonance), nasalance and speech acoustic variables also were assessed. Specifically, listener perception, intelligibility, and acoustics (vocal sound level in dB SPL, vowel space in formant frequency contours, DDK rates, proportion of consonant durations, and speaking rate in words per minute and syllables per second) were derived from each of the testing sessions shown in Figure 1. Table 4 describes the dependent variables and associated tasks used to derive their measurements. In addition, Table 4 indicates the type of quantitative or qualitative testing used to detect a behavioral change

Table 4. *Dependent variables across data collection points and type of analyses used to detect behavioral change across time points.*

Dependent Variables	Task	Pre LSVT	Post LSVT	Follow-up/Pre MS	Post MS	Statistical Analysis
1. Intelligibility	TOCS+ sentences judged by 4 unfamiliar listeners	✓	✓	✓	✓	Visual and Paired *t*-tests
2. Listener Perception "Preferred": loudness, loudness variation, pitch, pitch variation, articulatory precision, voice quality, resonance	Audio-taped sentence repetition task (untrained phrases) judged by 3 SLPs	✓	✓	✓	✓	Chi-Square (Goodness of Fit)
3. Nasalance Scores	Nasometry – Nasal sentences – Rainbow passage – Zoo passage	N/A	N/A	✓	✓	Visual
4. Acoustics						
Vocal Sound Level (dB SPL)	Untrained phrases	✓	✓	✓	✓	Visual and Paired *t*-tests
Vowel Space (formant frequency contours)	Corner vowels from untrained phrases	✓	✓	✓	✓	Visual
DDKs	AMRs and SMRs	✓	✓	✓	✓	Visual
Proportion of Consonant Durations	TOCS+ sentences	✓	✓	✓	✓	Visual and Paired *t*-tests
Speaking Rate (WPM)	TOCS+ sentences	✓	✓	✓	✓	Visual

Note. MS = motor speech, ✓ = present, TOCS+ = Test of Children's Speech Plus, DDKs = diadochokinetic rates, AMR = alternating motion rate, SMR = sequential motion rate, WPM = words per minute.

Data Analyses

Intelligibility. TOCS+ was used to obtain an intelligibility score from each child using a digital audio recording of imitated utterances from the four children in the present study. An open set procedure was used to evaluate word and sentence level intelligibility. Four naive listeners who passed a pure tone hearing-screening test (1000 Hz, 2000 Hz, and 4000 Hz at 20 dBHL) and did not have a background in speech-language training were recruited. These listeners were instructed to type into the computer keyboard what word or sentence they heard the child say. Listeners were only allowed to hear the word productions once but could listen to sentence productions a second time as needed. Listeners were randomly assigned children and were blind to testing session. Percent intelligibility was calculated for each listener by dividing the total number of words correctly identified by the total presented (n=80) and then averaged across listeners to derive a percent intelligibility score for each participant and test session.

Listener Perception. Three SLPs who specialize in voice and speech disorders were recruited to listen to and rate speech samples edited from the phrase repetitions, *Buy Bobby a puppy*, *The blue spot is on the key*, and *The potato stew is in the pot*. Randomized paired samples, were presented to each listener via a computer and headphones. Each listener was given the same instructions for making judgments on *preferred* loudness, loudness variability, pitch, pitch variability, resonance, articulatory precision and voice quality. Listeners were instructed to mark on a rating form, which sample they *preferred*: Sample A, Sample B, or no preference. A listening PowerPoint slide was created for each participant. The first two slides included a loud sample paired with a quiet sample, for the purposes of adjusting the volume to a comfortable listening level. Once adjusted, listeners were instructed not to change the output volume again throughout the listening session. The formal perceptual testing included 53 tracks of paired speech samples, across each time point for each child. The untrained phrases from the sentence repetition task were edited using Praat (Boersma & Weenink, 2015), to remove any clinician speech, and saved in individual .wav files. The tracks were then created by pairing the formatted .wav files across all four test sessions for each child using the commercial software program Audacity. An online randomization tool (Urbaniak & Plous, 2013) was used to determine the order in which the paired samples were presented to the listeners. Each paired sample was presented in both sequential and reverse ordering (i.e., pre-treatment followed by post-treatment, and post-treatment followed by pre-treatment). Therefore, two judgments on each paired sample were made by the three individual listeners, resulting in a total of six responses per variable.

Nasalance. Mean nasalance scores for the three recorded speech samples, were determined by calculating the ratio of sound pressure level (SPL) detected by the microphone under the nose and dividing it by the total SPL sensed by the nasal microphone and the oral microphone. Nasalance scores were expressed as a percentage.

Acoustic Variables. Acoustic measurements were used to provide understanding of related respiratory-laryngeal function and articulatory precision. These analyses included vocal sound levels (dB SPL), vowel space (formant frequency contours), proportion of consonant durations, speaking rate (words per minutes and syllables per second), and DDK performance. All measurements were obtained from recordings of the sentence repetition task (e.g., *Buy Bobby a puppy*) and the imitated sentences from TOCS+ using two software packages including TF32

(Milenkovic, 2005) and Praat (Boersma & Weenink, 2015).

Sound pressure measurements. The phrases from the sentence repetition task were edited using Praat, to remove any clinician speech, and saved in an individual .wav file. The .wav files were then opened in TF32 and a protocol was followed for obtaining values of dB SPL for each phrase during the vowel productions only. The mean dB SPL was recorded for each vowel in the phrase using the *RMS trace* function of TF32. An average dB SPL was then calculated across vowels for each phrase. Additionally, the dB SPL of the calibration tone for each recording session was analyzed using TF32. The value of the calibration tone derived from TF32 was subtracted (or added) from the value recorded by the sound level meter during the recording session, thus creating a correction factor. This correction factor was then applied to all dB SPL values produced by TF32, providing calibrated dB SPL at 10 cm mouth-to-microphone distance for each child and each recording session.

Vowel formant measurements. The edited .wav files containing the phrases from the sentence repetition task also were opened in TF32 and a protocol was followed for obtaining formant frequencies values for vowel space. F1, F2 and F3 values were recorded for */i/* from *key*, */u/* from stew, */a/* from *Bobby*. This was completed by selecting approximately 23 ms of the temporal midpoint of the vowel for /i/ and /*a*/, and the final 23 ms for the vowel /u/. The selection of the vowel was then opened using the *spec* function of TF32 and the frequency, in Hz, of the first (F1), second (F2) and third (F3) peaks were recorded.

Proportion of consonant durations. The digital audio recordings of imitated utterances recorded using TOCS+ were used to analyze proportion of consonant durations and speaking rate. For proportion of consonant durations, eight imitated phrases from TOCS+ were randomly selected for each child, across each time point, using an online randomization tool (Urbaniak & Plous, 2013). A detailed protocol was followed to insert boundaries at the onset and offset of each consonant and vowel contained in the eight phrases, using the *TextGrid* feature in Praat. Once all boundaries were placed, a custom developed Praat script was run to determine the duration of each phrase that consisted of consonants versus durations associated with vowels. Consonant proportions were then calculated by dividing the total duration of consonants by the total duration of consonants plus vowels, for each sentence at each time point.

Speaking rate. Speaking rate in words per minute (WPM) was calculated for each child by measuring the total duration of the phrase and the number of words spoken for each phrase recorded in TOCS+. To calculate WPM, the total duration of the speech sample (sum of the duration of all phrases in TOCS+) in minutes was divided by the total number of words in the speech sample (sum of the number of words included in all phrases in TOCS+). Additionally, syllables per second (SPS) was calculated by dividing the total duration of the speech sample (sum of the duration of all phrases in TOCS+) in seconds by the total number of syllables in the speech sample. Syllables per second were considered supplementary information and therefore were not used in the statistical analyses. However, the raw data are presented in Appendix A.

DDKs. Maximum Repetition Rate for Single Syllables (MRRmono) and Maximum Repetition Rate for Trisyllabic Sequences (MRRtri), were calculated using a detailed set of instructions presented by Rvachew and colleagues (2005). Specifically, measurement of MRRmono was accomplished by opening the sound file in TF32 and marking off 10 consecutive repetitions of the syllable. It was required that all 10 repetitions be produced on a single breath and could not include the initial syllable after an inspiration or the last syllable before an inspiration. In order to obtain the number of syllables per second, the number of syllables (10) was divided by the total time it took for the participant to produce ten syllables, in seconds. A similar procedure was used to measure MRRtri. However, 4 consecutive repetitions of the sequence /pɑtɑkɑ/ (12 syllables) were included. The number of syllables per second was calculated by dividing the number of syllables (12) by the total time it took for the participant to produce the sequence (Rvachew et al., 2005).

Statistical Analyses

When quantification of data was possible, statistical methods were applied to the data. However, due to the nature of single-subject designs, non-parametric tests such as chi-square and visual inspection across multiple measures were used. Paired *t*-tests were used to analyze measures containing multiple trials (intelligibility, dB SPL, and proportion of consonant durations) in order to compare the performance across the four different time points for each participant. Prior to running a paired *t*-test, each participant's measurements for each trial within a session were visualized and compared across sessions. Autocorrelations were run on trials within a session to rule out serial dependency and performance trending. There were no instances of significant correlations indicating that the values did not have serial dependency, thus employing the *t*-statistic to test differences in performance between sessions was justified. For studies containing large sample sizes or those in later phases of efficacy research, reducing the chances of obtaining false-positive results (*Type I* error), when multiple pair-wise tests are performed on a single set of data is important. Typically a *Bonferroni* correction or other correction process is used. However, this is an exploratory, single case, *Phase I* study thus, liberal tolerances for *Type I* and *Type II* errors are appropriate (Robey & Schultz, 1998). In other words, during early phases of treatment research it is important to detect a possible treatment effect at the risk of a potential *Type I* error (Robey & Schultz, 1998). Therefore, a lenient uncorrected p value of 0.05 was used. In the case of proportion of consonant durations, a p value of 0.06 was an indication of a statistical trend.

Pearson correlation coefficients were computed to determine whether there was a relationship between averaged consonant proportions and speaking rate for the same eight TOCS+ phrases, as well as averaged consonant proportions and percent intelligibility, for each child.

A chi-square goodness of fit was used to analyze listener preferences on loudness, loudness variability, pitch, pitch variability, resonance, vocal quality and articulatory precision. This test for nominal data determined whether or not the observed distribution of perceptual judgments reported from listeners differed significantly from what might have been expected by chance alone.

Visual analysis was used for variables containing only one observation per recording session (nasalance scores, vowel space, DDKs, and WPM) or when inferential statistical assumptions could not be met.

Reliability

Inter-measurer reliability was calculated by having 10% of data reanalyzed by a second measurer for dB SPL, WPM, proportion of consonant durations, and vowel space. Pearson correlations (r) were calculated indicating inter-measurer reliability scores as follows: dB SPL $r = 0.997$, $p < 0.0001$; WPM $r = 0.995$, $p < 0.0001$; proportion of consonant durations $r = 0.606$, $p = 0.01$; and vowel space $r = 0.747$, $p < 0.0001$. These values represent good inter-measurer reliability.

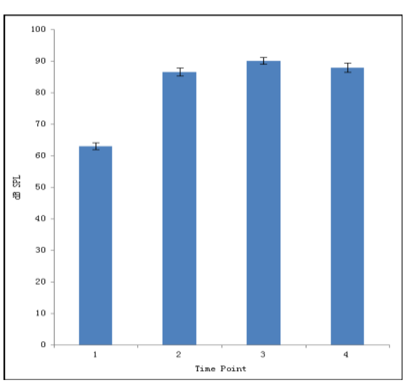
Intra-measurer reliability was calculated by having 10% of data reanalyzed by the same measurer for dB SPL, WPM, proportion of consonant durations, and vowel space. Pearson correlations (r) were calculated indicating intra-measurer reliability scores as follows: dB SPL $r = 0.970$, $p < 0.0001$; WMP $r = 0.996$, $p < 0.0001$; proportion of consonant durations $r = 0.791$, $p < 0.0001$; and vowel space $r = 0.939$, $p < 0.0001$. These values represent good intra-measurer reliability.

Results

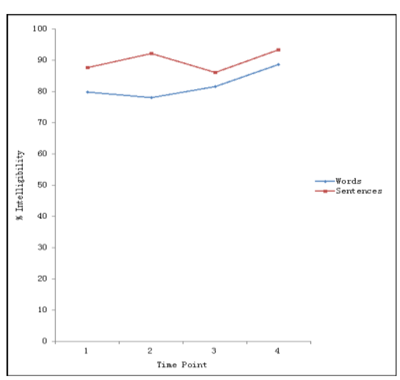
lsvtf1

At the time of initial testing lsvtf1, a thirteen-year-old female, had a diagnosis of mixed dysarthria and mild CAS. Modulating loudness was her main target during LSVT LOUD and /θ/ and /g/ were her speech sound targets during motor speech treatment. Please refer to Table 2 and Table 3 for a more detailed description of the treatment schedule and repetition dose for LSVT LOUD and motor speech treatment, respectively. Figure 2 depicts visual analyses for the variables dB SPL (A), intelligibility (B), nasalance scores (C), speaking rate (D), DDK performance (E), and proportion of consonant durations (F).

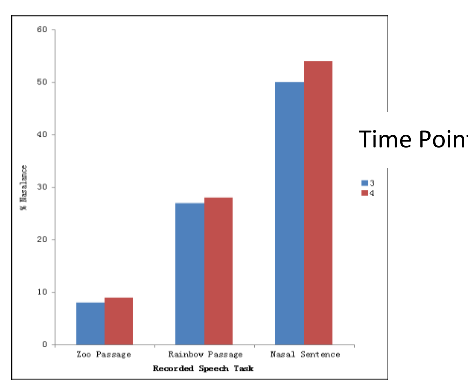
A.



B.



C.



D. E. F.

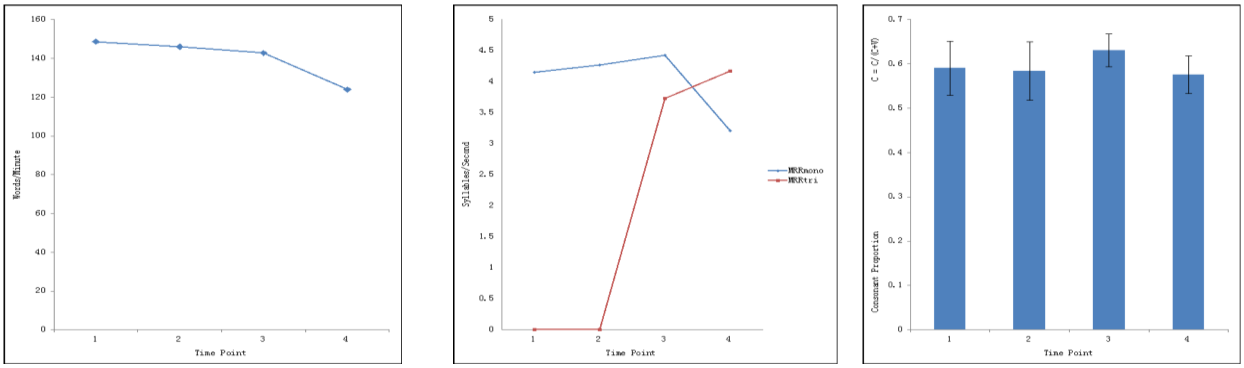


Figure 2. Visual analyses for lsvtf1 data, across all time points. Where A = Vocal Sound Levels (dB SPL, mouth-to-microphone distance = 10 cm), B = Percent Intelligibility, C = Nasalance Scores, D = Speaking Rate, E = DDKs, F = Consonant Proportions; and Time Point 1 = pre LSVT LOUD, 2 = post LSVT LOUD, 3 = follow-up LSVT LOUD/pre motor speech, and 4 = post motor speech. Note: Time Points 2 and 4 are indicated by tic marks only on Panel B (Intelligibility).

Vocal Sound Level (dB SPL). Follow-up paired *t*-tests showed that the differences between all conditions were statistically significant. Vocal sound level (dB SPL) was significantly different between: pre- and post-LSVT LOUD (t = 49.156, df = 8, $p < 0.0001$, one tailed); pre-LSVT LOUD and follow-up LSVT LOUD/pre-motor speech (t = 78.782, df = 8, $p < 0.0001$, one tailed); pre-LSVT LOUD and post-motor speech (t = 35.000, df = 8, $p < 0.0001$, one tailed); post-LSVT LOUD and follow-up LSVT LOUD/pre motor speech (t = 6.525, df = 8, $p < 0.0001$, one tailed); post-LSVT LOUD and post-motor speech (t = 2.517, df = 8, p = 0.02, one tailed). However, dB SPL was significantly lower between follow-up LSVT LOUD/pre motor speech and post-motor speech (t = 2.890, df = 8, p = 0.02, two tailed).

Intelligibility. Paired *t*-tests showed that percent intelligibility for both words and sentences, was significantly different between: pre-LSVT LOUD and post-motor speech treatment (words: t = 9.890, df = 3, p = 0.0001, one tailed; sentences: t = 8.319, df = 3, p = 0.002, one tailed); post-

LSVT LOUD treatment and post-motor speech treatment (words: $t = 2.537$, df = 3, $p = 0.04$, one tailed); and follow-up LSVT LOUD/pre motor speech and post-motor speech treatment (words: $t = 4.372$, df = 3, $p = 0.01$, one tailed; sentences: $t = 2.644$, df = 3, $p = 0.04$, one tailed).

Nasalance Scores. Percent nasalance increased slightly in the direction of values derived from typically developing children post-motor speech, across all three recorded speech tasks. However, post-motor speech treatment, percent nasalance for nasal sentences was the only value to fall within one standard deviation of scores obtained for typical English speaking children (Baken & Orlikoff, 2000).

Speaking Rate (WPM). lsvtf1 demonstrated a reduction in speaking rate across all four time points with the greatest decrease occurring following motor speech treatment. A total drop in speaking rate from approximately 150 WPM to 120 WPM was observed between pre-LSVT LOUD and post-motor speech treatment.

DDKs. lsvtf1's number of SPS (MRRmono) during the AMR task, increased from pre-LSVT LOUD treatment to post-LSVT LOUD, and increased again at follow-up LSVT LOUD/pre motor speech treatment. However, number of syllables per second for AMRs decreased following motor speech treatment. lsvtf1 was unable to produce four consecutive repetitions of /pɑtɑkɑ/ (MRRtri) pre- or post-LSVT LOUD but was able to successfully complete this task following the 12-week maintenance program and again following motor speech treatment.

Proportion of Consonant Durations. A paired *t*-test showed that the consonant proportion was significantly smaller from follow-up LSVT LOUD/pre motor speech to post-motor speech treatment ($t = 2.455$, df = 7, $p = 0.04$, two tailed). A Spearman's correlation revealed a significant negative correlation between intelligibility on sentences and consonant proportion ($rho = -1.000$, N = 4, $p < 0.01$, two tailed). However, the time point that displayed the lowest consonant proportion matched with the highest percent intelligibility rating, for both words and sentences, suggesting a relationship between consonant proportion and intelligibility ratings. There was no significant correlation found between speaking rate and consonant proportion for lsvtf1.

Vowel Space. Figure 3 shows formant frequency values for the corner vowels /i/, /ɑ/, and /u/, across all time points for lsvtf1, as well as normative data from typically developing children. Following motor speech treatment, lsvtf1 demonstrated an increase in vowel space for /ɑ/. However, F1 values for both /i/ and /u/ were pulled farther away from what would be expected based on values from typically developing children. This suggests that although lsvtf1 was able to lower her tongue position when producing a low vowel, following treatment, her tongue position for high vowels was lowered as well.

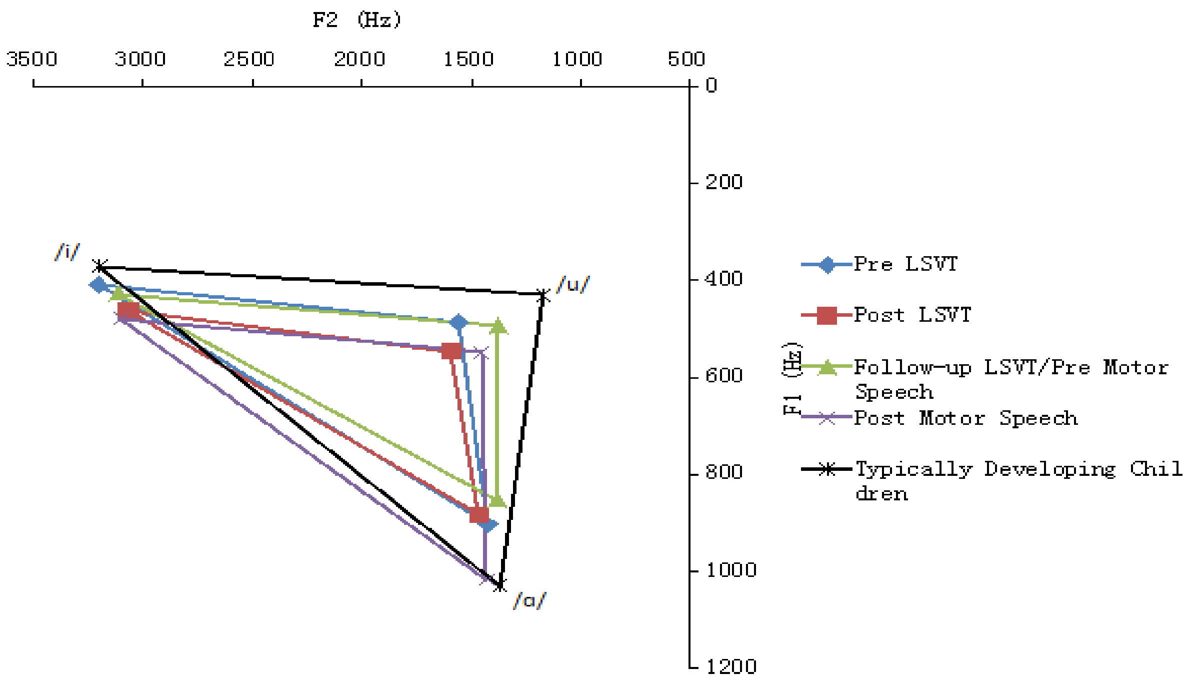


Figure 3. Corner vowel formant frequencies across all time points for lsvtf1, and normative data for typically developing children. Formant frequency values for the corner vowels /i/, /ɑ/, and /u/, across all time points depicted in different colors (pre-LSVT LOUD = blue; post-LSVT LOUD = red; follow-up LSVT LOUD/Pre-Motor Speech Tx = green; Post-Motor Speech Tx = purple) against the normative data for typically developing children of the same age range depicted in black.

Listener Perception. Table 5 shows a summary of the Chi-square analyses for clinician preference on perceptual variables of voice and speech, for lsvtf1, across all four time points.

Table 5. *Summary Chi-square statistics for lsvtf1 on clinician preference for voice and speech produced on un-trained sentences pre- LSVT-, post- LSVT, follow-up LSVT/pre Motor Speech and post Motor Speech.*

Variable	PreLSVT	PostLSVT	NP	Sig	χ^2
Loudness	1	1	4	0.223	3.00
Loudness Variability	2	2	2	1.000	0.00
Pitch	0	1	**5***	0.030	7.00
Pitch Variability	1	2	3	0.607	1.00
Closer to Normal Resonance	2	0	4	0.135	4.00
Voice Quality	0	0	**6***	0.002	12.0
Articulatory Precision	2	2	2	1.000	0.00
Variable	PreLSVT	FuLSVT/PreMS	NP	Sig	χ^2

Loudness	1	1	4	0.223	3.00
Loudness Variability	1	2	3	0.607	1.00
Pitch	0	0	**6***	0.002	12.0
Pitch Variability	1	1	4	0.223	3.00
Closer to Normal Resonance	1	0	**5***	0.030	7.00
Voice Quality	1	2	3	0.607	1.00
Articulatory Precision	0	1	**5***	0.030	7.00
Variable	PreLSVT	PostMS	NP	Sig	χ^2
Loudness	3	2	1	0.607	1.00
Loudness Variability	3	2	1	0.607	1.00
Pitch	0	1	**5***	0.030	7.00
Pitch Variability	1	3	2	0.607	1.00
Closer to Normal Resonance	0	1	**5***	0.030	7.00
Voice Quality	0	2	4	0.135	4.00
Articulatory Precision	1	2	3	0.607	1.00
Variable	PostLSVT	FuLSVT/PreMS	NP	Sig	χ^2
Loudness	1	2	3	0.607	1.00
Loudness Variability	1	4	1	0.223	3.00
Pitch	0	1	**5***	0.030	7.00
Pitch Variability	0	3	3	0.223	3.00
Closer to Normal Resonance	0	1	**5***	0.030	7.00
Voice Quality	1	1	4	0.223	3.00
Articulatory Precision	0	3	3	0.223	3.00
Variable	PostLSVT	PostMS	NP	Sig	χ^2
Loudness	2	1	3	0.607	1.00
Loudness Variability	2	2	2	1.000	0.00
Pitch	0	0	**6***	0.002	12.0
Pitch Variability	0	4	2	0.135	4.00
Closer to Normal Resonance	0	4	2	0.135	4.00
Voice Quality	1	2	3	0.607	1.00
Articulatory Precision	0	3	3	0.223	3.00
Variable	FuLSVT/PreMS	PostMS	NP	Sig	χ^2
Loudness	4	0	2	0.135	4.00
Loudness Variability	2	2	2	1.000	0.00
Pitch	1	0	**5***	0.030	7.00
Pitch Variability	2	1	3	0.607	1.00
Closer to Normal Resonance	0	3	3	0.223	3.00
Voice Quality	2	2	2	1.000	0.00
Articulatory Precision	1	2	3	0.607	1.00

Note. NP = no preference; Fu = follow-up; MS = Motor Speech; Sig = level of statistical significance; χ2 = chi squared value. The bold and asterisk value indicates the preference (PreLSVT, PostLSVT, FuLSVT/PreMS, PostMS) that was statistically significant.

Clinicians had no preference between: pre- and post-LSVT LOUD for pitch (χ^2 = 7.00, p = 0.03), and voice quality (χ^2 = 12.00, p = 0.002); pre-LSVT LOUD and follow-up LSVT

LOUD/pre motor speech for pitch (χ^2 = 12.00, p = 0.002), closer to normal resonance (χ^2 = 7.00, p = 0.03), and articulatory precision (χ^2 = 7.00, p = 0.03); pre-LSVT LOUD and post-motor speech for pitch (χ^2 = 7.00, p = 0.03), and closer to normal resonance (χ^2 = 7.00, p = 0.03); post-LSVT LOUD and follow-up LSVT LOUD/pre motor speech for pitch (χ^2 = 7.00, p = 0.03), and closer to normal resonance (χ^2 = 7.00, p = 0.03); post-LSVT LOUD and post-motor speech for pitch (χ^2 =12.00, p = 0.002); and follow-up LSVT LOUD/pre motor speech to post-motor speech for pitch (χ^2 = 7.00, p = 0.03) indicating that there were no perceived changes in overall pitch, voice quality, resonance, and articulatory precision, for lsvtf1, between the specified time points. All other preferences for voice and speech variables were not statistically significant for lsvtf1.

lsvtf3

At the time of initial testing lsvtf3, a twelve-year-old female, presented with a diagnosis of mixed dysarthria and mild CAS. Modulating loudness was her main target during LSVT LOUD and /ʃ/, /k/, /ɡ/, and /ŋ/ were her speech sound targets during motor speech treatment. Please refer to Table 2 and Table 3 for a more detailed description of the treatment schedule and repetition dose for LSVT LOUD and motor speech treatment, respectively. Figure 4 depicts visual analyses for the variables dB SPL (A), intelligibility (B), nasalance scores (C), speaking rate (D), DDK performance (E), and proportion of consonant durations (F).

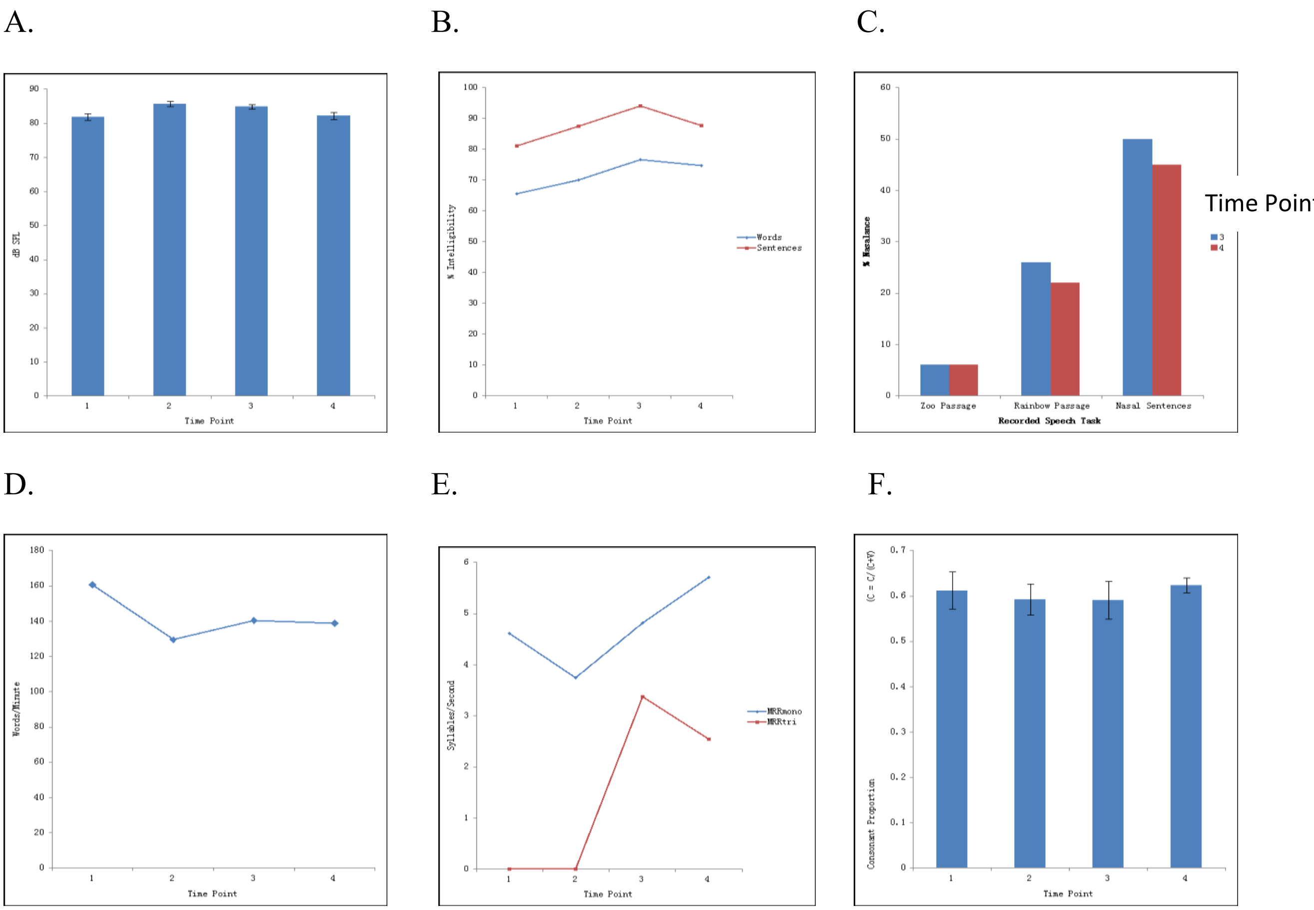


Figure 4. Visual analyses for lsvtf3 data, across all time points. Where A = Vocal Sound Levels (dB SPL, mouth-to-microphone distance = 10 cm), B = Percent Intelligibility, C = Nasalance Scores, D = Speaking Rate, E =DDKs, F = Consonant Proportions; and Time Point 1 = pre LSVT LOUD, 2 = post LSVT LOUD, 3 = follow-up LSVT LOUD/pre motor speech, and 4 = post motor speech. Note: Time Points 2 and 4 are indicated by tic marks only on Panel B (Intelligibility).

Vocal Sound Level (dB SPL). Follow-up paired *t*-tests showed statistically significant differences between most conditions. Vocal sound level (db SPL) was significantly different between: pre- and post-LSVT LOUD ($t = 11.533$, df = 8, $p < 0.0001$, one tailed) and pre-LSVT LOUD and follow-up LSVT LOUD/pre motor speech ($t = 7.711$, df = 8, $p < 0.0001$, one tailed). dB SPL was not maintained between: post-LSVT LOUD and follow-up LSVT LOUD/pre motor speech ($t = 3.275$, df = 8, $p = 0.01$, two tailed); post-LSVT LOUD and post-motor speech ($t =$

9.994, df = 8, $p < 0.0001$, two tailed); and follow-up LSVT LOUD/pre motor speech and post-motor speech ($t = 6.299$, df = 8, $p < 0.0001$, two tailed).

Intelligibility. Follow-up paired *t*-test showed that percent intelligibility for both words and sentences, were significantly different between: pre- and post-LSVT LOUD (sentences: $t = 3.397$, df = 3, $p = 0.02$, one tailed); pre-LSVT LOUD to follow-up LSVT LOUD/pre motor speech (words: $t = 8.163$, df = 3, $p = 0.002$, one tailed; sentences: $t = 9.944$, df = 3, $p = 0.001$, one tailed); pre-LSVT LOUD to post-motor speech (words: $t = 3.427$, df = 3, $p = 0.02$, one tailed; sentences: $t = 3.178$, df = 3, $p = 0.025$, one tailed); and post-LSVT LOUD and follow-up LSVT LOUD/pre motor speech (sentences: $t = 3.656$, df = 3, $p = 0.02$, one tailed).

Nasalance Scores. Percent nasalance either stayed the same (as in the zoo passage) or decreased slightly (as in the rainbow passage and nasal sentences) from follow-up LSVT LOUD/pre motor speech to post-motor speech, resulting in values that moved farther away from normative values (Baken & Orlikoff, 2000).

Speaking Rate (WPM). lsvtf3 demonstrated a reduction in speaking rate following LSVT LOUD treatment. Her speaking rate increased again at follow-up LSVT LOUD/pre motor speech, and remained relatively constant following motor speech treatment.

DDKs. lsvtf3's number of SPS (MRRmono) during the AMR task decreased immediately following LSVT LOUD treatment, and increased at follow-up LSVT LOUD/pre motor speech and again at post-motor speech treatment. lsvtf3 was unable to correctly sequence the tri-syllabic repetition, /pɑtɑkɑ/ (MRRtri) pre- or post-LSVT LOUD treatment, but was able to produce the sequence for less than four repetitions at follow-up LSVT LOUD/pre motor speech and post-motor speech. However, her number of syllables per second for MRRtri decreased following motor speech treatment.

Proportion of Consonant Durations. A follow-up paired *t*-test showed that the consonant proportions were significantly larger from post-LSVT LOUD to post-motor speech ($t = 4.025$, df $= 7$, $p = 0.005$, two tailed). A Pearson correlation revealed no significant relationship between intelligibility (words and sentences) and consonant proportion. However, the time point that displayed the lowest consonant proportion matched the highest percent intelligibility rating, for both words and sentences, suggesting a relationship between consonant proportions and intelligibly ratings. There was no significant correlation between speaking rate and consonant proportion for lsvtf3.

Vowel Space. Figure 5 shows formant frequency values for the corner vowels /i/, /ɑ/, and /u/, across all time points for lsvtf3, as well as normative data for typically developing children. From pre-LSVT LOUD to follow-up LSVT LOUD/pre motor speech, lsvtf3 demonstrated a decrease in F2 and in increase in F1 for /ɑ/, bringing these formant frequencies values closer to what would be expected for typically developing speech. Formant frequencies for the vowels /i/ and /u/ remained fairly constant across the first three time points. However, following motor speech treatment, lsvtf3 displayed an increase in F2 for /i/, a decrease in F2 for /u/, and an increase in F1 for /u/, resulting in formant frequencies for high vowels that approximate those expected in typically developing child speech.

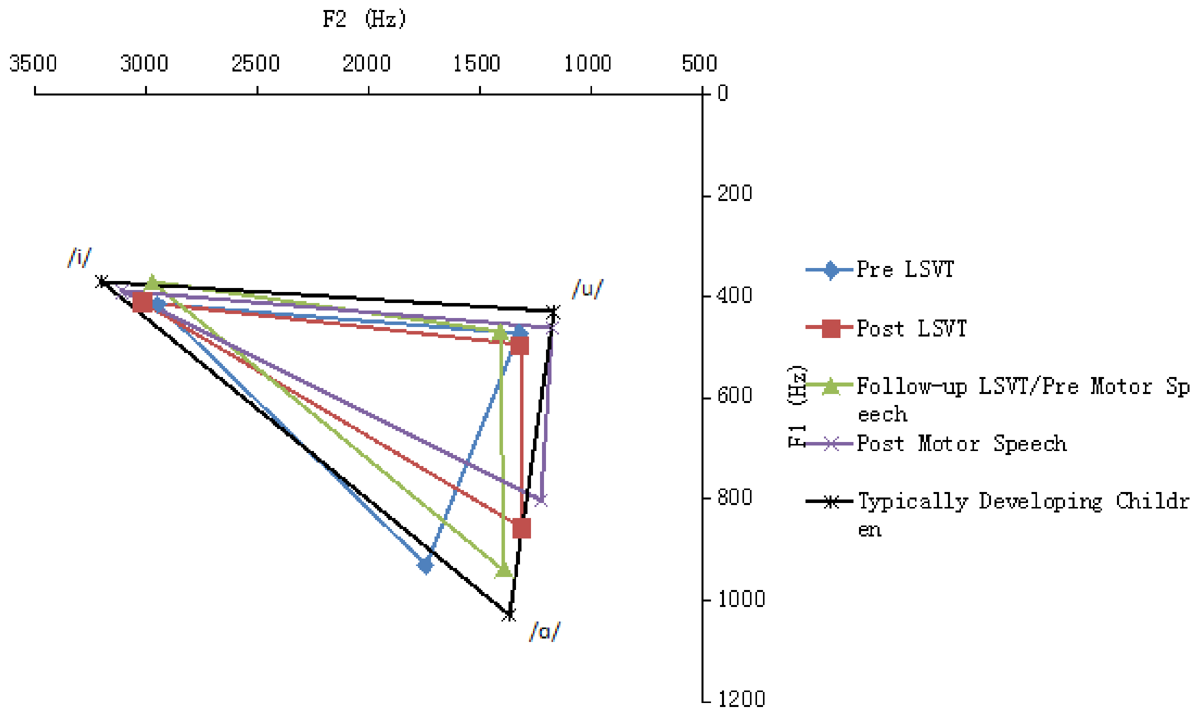


Figure 5. Corner vowel formant frequencies across all time points for lsvtf3, and normative data for typically developing children. Formant frequency values for the corner vowels /i/, /ɑ/, and /u/, across all time points depicted in different colors (pre-LSVT LOUD = blue; post-LSVT LOUD = red; follow-up LSVT LOUD/Pre-Motor Speech Tx = green; Post-Motor Speech Tx = purple) against the normative data for typically developing children of the same age range depicted in black.

Listener Perception. Table 6 shows a summary of the Chi-square analyses for clinician preference on perceptual variables of voice and speech, for lsvtf3, across all four time points.

Table 6. *Summary Chi-square statistics for lsvtf3 on clinician preference for voice and speech produced on un-trained sentences pre- LSVT-, post- LSVT, follow-up LSVT/pre Motor Speech and post Motor Speech.*

Variable	PreLSVT	PostLSVT	NP	Sig	χ^2
Loudness	1	3	2	0.607	1.00
Loudness Variability	0	2	4	0.135	4.00
Pitch	0	0	**6***	0.002	12.0
Pitch Variability	2	2	2	1.000	0.00
Closer to Normal Resonance	0	0	**6***	0.002	12.0
Voice Quality	0	2	4	0.135	4.00
Articulatory Precision	0	**6***	0	0.002	12.0

Variable	PreLSVT	FuLSVT/PreMS	NP	Sig	χ^2
Loudness	0	1	**5***	0.03	7.00
Loudness Variability	1	1	4	0.223	3.00
Pitch	0	1	**5***	0.030	7.00
Pitch Variability	3	3	0	0.223	3.00
Closer to Normal Resonance	0	0	**6***	0.002	12.0
Voice Quality	1	2	2	0.819	0.40
Articulatory Precision	0	**6***	0	0.002	12.0
Variable	PreLSVT	PostMS	NP	Sig	χ^2
Loudness	2	2	2	1.000	0.00
Loudness Variability	0	2	4	0.135	4.00
Pitch	2	0	4	0.135	4.00
Pitch Variability	4	2	0	0.135	4.00
Closer to Normal Resonance	1	0	4		
Voice Quality	1	0	**5***	0.030	7.00
Articulatory Precision	0	**6***	0	0.002	12.0
Variable	PostLSVT	FuLSVT/PreMS	NP	Sig	χ^2
Loudness	4	0	2	0.135	4.00
Loudness Variability	1	1	4	0.223	3.00
Pitch	1	0	**5***	0.030	7.00
Pitch Variability	1	1	4	0.223	3.00
Closer to Normal Resonance	1	0	**5***	0.030	7.00
Voice Quality	2	1	3	0.607	1.00
Articulatory Precision	2	1	3	0.607	1.00
Variable	PostLSVT	PostMS	NP	Sig	χ^2
Loudness	3	1	2	0.607	1.00
Loudness Variability	3	2	1	0.607	1.00
Pitch	2	0	4	0.135	4.00
Pitch Variability	3	1	2	0.607	1.00
Closer to Normal Resonance	0	0	**6***	0.002	12.0
Voice Quality	1	1	4	0.223	3.00
Articulatory Precision	2	1	3	0.607	1.00
Variable	FuLSVT/PreMS	PostMS	NP	Sig	χ^2
Loudness	3	1	2	0.607	1.00
Loudness Variability	3	2	1	0.607	1.00
Pitch	2	0	4	0.135	4.00
Pitch Variability	1	1	4	0.223	3.00
Closer to Normal Resonance	0	0	**6***	0.002	12.0
Voice Quality	2	0	4	0.135	4.00
Articulatory Precision	2	0	4	0.135	4.00

Note. NP = no preference; Fu = follow-up; MS = Motor Speech; Sig = level of statistical significance; $\chi 2$ = chi squared value. The bold and asterisk value indicates the preference (PreLSVT, PostLSVT, FuLSVT/PreMS, PostMS) that was statistically significant.

Preference for articulatory precision post-treatment was statistically significant for: pre- and post-LSVT LOUD (χ^2 =12.00, p = 0.002); pre-LSVT LOUD and follow-up LSVT LOUD/pre motor speech (χ^2 =12.00, p = 0.002); and pre-LSVT LOUD and post-motor speech (χ^2 =12.00, p = 0.002). Clinicians had no preference between: pre- and post-LSVT LOUD for pitch (χ^2 = 12.00, p = 0.002), and closer to normal resonance (χ^2 = 12.00, p = 0.002); pre-LSVT LOUD and follow-up LSVT LOUD/pre motor speech for loudness (χ^2 = 7.00, p = 0.03), pitch (χ^2 = 7.00, p = 0.03), and closer to normal resonance (χ^2 = 12.00, p = 0.002); pre-LSVT LOUD and post-motor speech for voice quality (χ^2 = 7.00, p = 0.03); post-LSVT LOUD and follow-up LSVT LOUD/pre motor speech for pitch (χ^2 = 7.00, p = 0.03), and closer to normal resonance (χ^2 = 7.00, p = 0.03). Clinicians also had no preference for closer to normal resonance between: post-LSVT LOUD and post-motor speech (χ^2 =12.00, p = 0.002); and follow-up LSVT LOUD and post-motor speech (χ^2 =12.00, p = 0.002) indicating that there were no perceived changes in overall loudness, overall pitch, voice quality, and resonance, for lsvtf3, between the specified time points. All other preferences for voice and speech variables were not statistically significant for lsvtf3.

lsvtf7

At the time of initial testing lsvtf7, a sixteen-year-old female, had a diagnosis of mixed dysarthria and severe CAS. Increasing vocal loudness was her main target during LSVT LOUD treatment, /ɛ/, /p/, /b/, functional phrases, and communication repair strategies were her targets during motor speech treatment. Please refer to Table 2 and Table 3 for a more detailed description of the treatment schedule and repetition dose for LSVT LOUD and motor speech treatment, respectively. Figure 6 depicts visual analyses for the variables dB SPL (A), intelligibility (B), nasalance scores (C), speaking rate (D), DDK performance (E), and proportion of consonant durations (F).

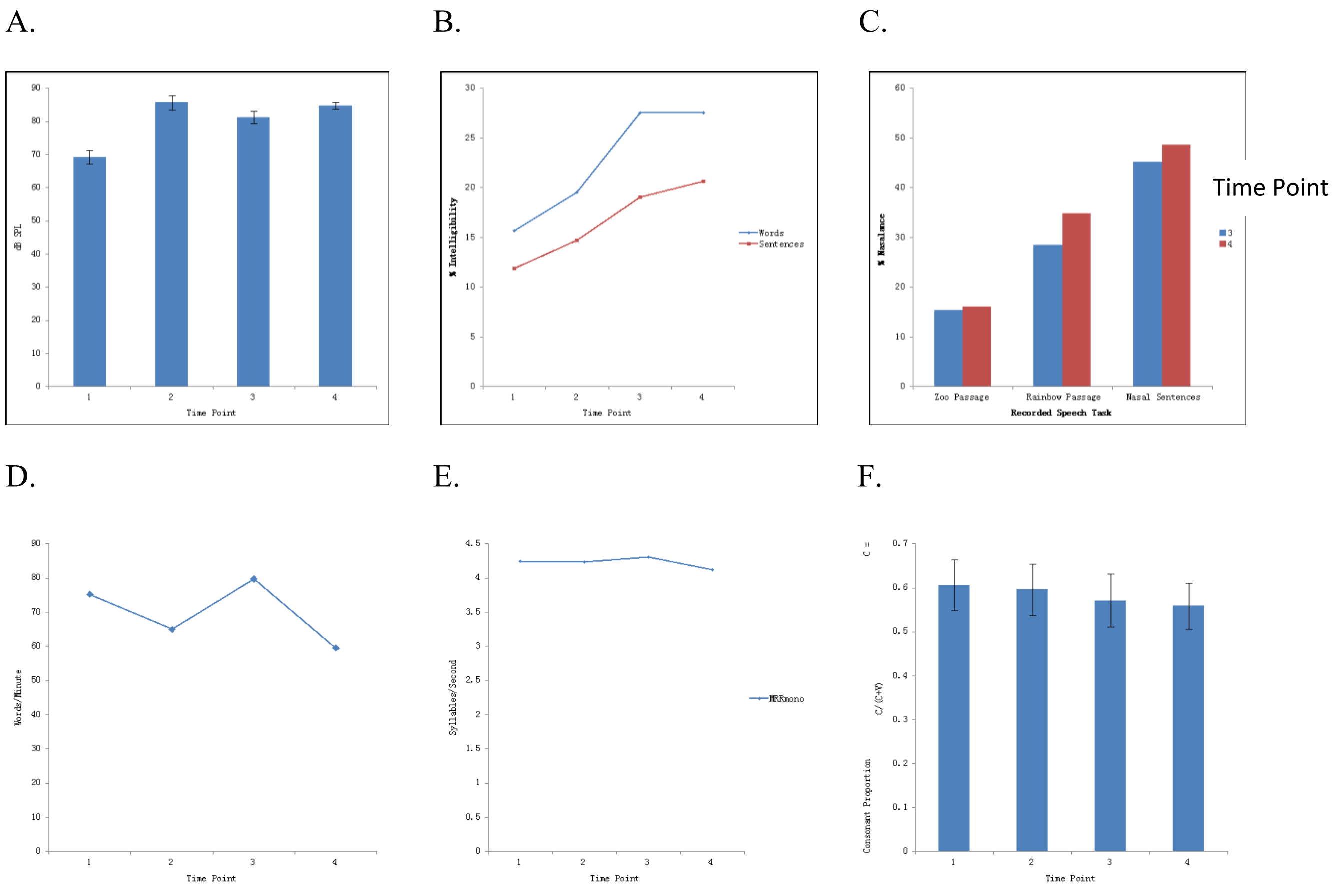


Figure 6. Visual analyses for lsvtf7 data, across all time points. Where A = Vocal Sound Levels (dB SPL, mouth-to-microphone distance = 10 cm), B = Percent Intelligibility, C = Nasalance Scores, D = Speaking Rate, E =DDKs, F = Consonant Proportions; and Time Point 1 = pre LSVT LOUD, 2 = post LSVT LOUD, 3 = follow-up LSVT LOUD/pre motor speech, and 4 = post motor speech. Note: Time Points 2 and 4 are indicated by tic marks only on Panel B (Intelligibility).

Vocal Sound Level (dB SPL). Paired *t*-tests showed statistically significant differences between most conditions. Vocal sound level (db SPL) was significantly different between: pre- and post-LSVT LOUD ($t = 16.361$, df = 8, $p < 0.0001$, one tailed); pre-LSVT LOUD and follow-up LSVT LOUD/pre motor speech ($t = 11.980$, df = 8, $p < 0.0001$, one tailed); pre-LSVT LOUD and post-motor speech ($t = 21.358$, df = 8, $p < 0.0001$, one tailed); follow-up LSVT LOUD/pre motor speech and post-motor speech ($t = 5.628$, df = 8, $p < 0.0001$, one tailed). However, dB

SPL was not maintained from post-LSVT LOUD to follow-up LSVT LOUD/pre motor speech ($t = 4.191$, df = 8, $p = 0.003$, two tailed).

Intelligibility. Follow-up paired *t*-tests showed that percent intelligibility for both words and sentences, were significantly different between: pre-LSVT LOUD and follow-up LSVT LOUD/pre motor speech (words: $t = 3.226$, df = 3, $p = 0.02$, one tailed); and pre-LSVT LOUD and post-motor speech (words: $t = 4.588$, df = 3, $p = 0.01$, one tailed; sentences: $t = 2.378$, df = 3, $p = 0.05$, one tailed).

Nasalance Scores. Percent nasalance increased slightly from follow-up LSVT LOUD/pre motor speech to post-motor speech, across all three recorded speech tasks. For the zoo passage, percent nasalance remained within one standard deviation of nasalance scores obtained from normative data. For the production of nasal sentences, percent nasalance moved in the direction of, but did not fall within one standard deviation of expected values for typically developing children. However, lsvtf7's percent nasalance score for the rainbow passage reached normative values following motor speech treatment (Baken & Orlikoff, 2000).

Speaking Rate (WPM). lsvtf7 demonstrated a reduction in speaking rate following LSVT LOUD treatment. Her speaking rate increased again at follow-up LSVT LOUD/pre motor speech, but decreased again following motor speech treatment.

DDKs. The number of syllables per second (MRRmono), that lsvtf7 was able to produce for the AMR task, remained relatively constant pre- to post-LSVT LOUD and again at follow-up LSVT LOUD/pre motor speech. However, following motor speech treatment a decrease in syllables per second during the AMR task was exhibited. lsvtf7 was unable to successfully produce the tri-syllabic repetition, /pɑtɑkɑ/, at any of the four time points.

Proportion of Consonant Durations. Paired *t*-tests showed that the differences found in consonant proportions were not statistically significant ($p > 0.06$, two tailed). A Pearson's correlation revealed a significant negative correlation between intelligibility, for both words and sentences, and consonant proportion (words: $r = -0.969$, N = 4, $p = 0.02$, one tailed; sentences: $r = -0.992$, N = 4, $p = 0.004$, one tailed). Consonant proportions decreased while intelligibility ratings increased, across all four time points. There was no significant correlation found between speaking rate and consonant proportion for lsvtf7.

Vowel Space. Figure 7 shows formant frequency values for the corner vowels /i/, /ɑ/, and /u/, across all time points for lsvtf7, as well as normative data from typically developing children. From pre-LSVT LOUD to post-motor speech treatment, lsvtf7 demonstrated a decrease in F1 for /i/ and F2 for /u/, and an increase in F1 for /ɑ/, resulting in formant frequency values that approach those expected in typically developing child speech.

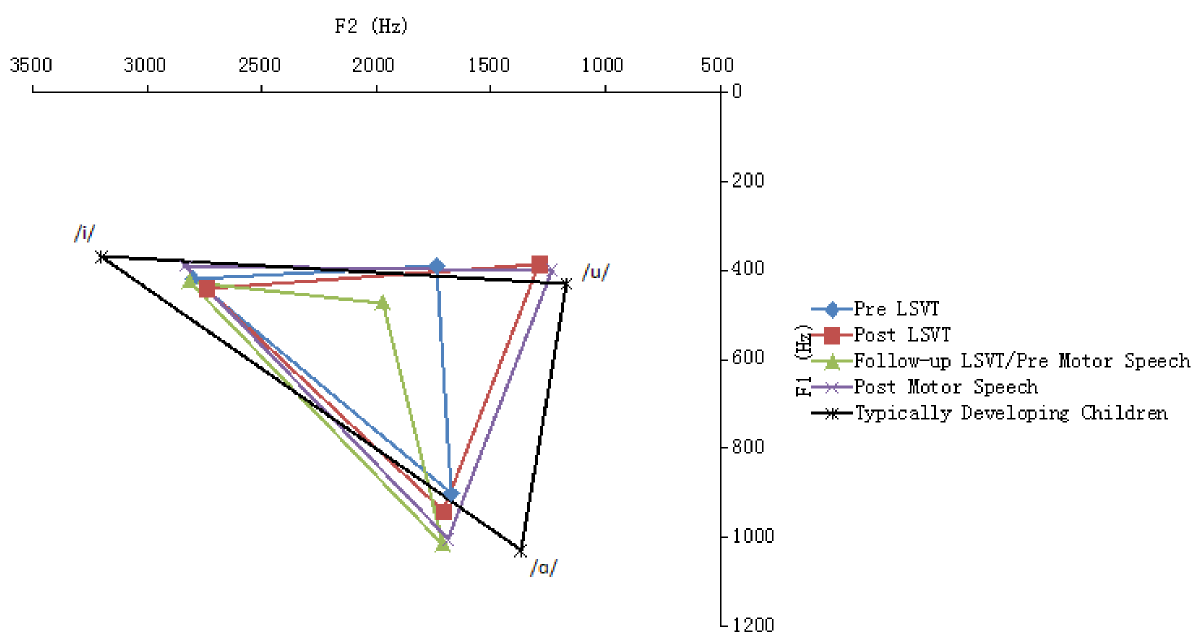


Figure 7. Corner vowel formant frequencies across all time points for lsvtf7, and normative data

for typically developing children. Formant frequency values for the corner vowels /i/, /ɑ/, and /u/, across all time points depicted in different colors (pre-LSVT LOUD = blue; post-LSVT LOUD = red; follow-up LSVT LOUD/Pre-Motor Speech Tx = green; Post-Motor Speech Tx = purple) against the normative data for typically developing children of the same age range depicted in black.

Listener Perception. Table 7 shows a summary of the Chi-square analyses for clinician preference on perceptual variables of voice and speech, for lsvtf7, across all four time points.

Table 7. *Summary Chi-square statistics for lsvtf7 on clinician preference for voice and speech produced on un-trained sentences pre- LSVT-, post- LSVT, follow-up LSVT/pre Motor Speech and post Motor Speech.*

Variable	PreLSVT	PostLSVT	NP	Sig	χ^2
Loudness	2	1	3	0.607	1.00
Loudness Variability	3	0	3	0.223	3.00
Pitch	0	0	**6***	0.002	12.0
Pitch Variability	1	0	**5***	0.030	7.00
Closer to Normal Resonance	0	0	**6***	0.002	12.0
Voice Quality	0	0	**6***	0.002	12.0
Articulatory Precision	0	1	**5***	0.030	7.00
Variable	PreLSVT	FuLSVT/PreMS	NP	Sig	χ^2
Loudness	3	2	1	0.607	1.00
Loudness Variability	1	3	2	0.607	1.00
Pitch	2	0	4	0.135	4.00
Pitch Variability	2	1	3	0.607	1.00
Closer to Normal Resonance	2	2	2	1.000	0.00
Voice Quality	1	1	4	0.223	3.00
Articulatory Precision	2	2	2	1.000	0.00
Variable	PreLSVT	PostMS	NP	Sig	χ^2
Loudness	1	2	1	0.223	3.00
Loudness Variability	1	1	4	0.223	3.00
Pitch	0	1	**5***	0.030	7.00
Pitch Variability	2	1	3	0.607	1.00
Closer to Normal Resonance	1	1	4	0.223	3.00
Voice Quality	2	2	2	1.000	0.00
Articulatory Precision	1	3	2	0.607	1.00
Variable	PostLSVT	FuLSVT/PreMS	NP	Sig	χ^2
Loudness	2	1	3	0.607	1.00
Loudness Variability	0	0	**6***	0.002	12.0
Pitch	0	0	**6***	0.002	12.0
Pitch Variability	0	1	**5***	0.030	7.00
Closer to Normal Resonance	0	1	**5***	0.030	7.00
Voice Quality	0	1	**5***	0.030	7.00
Articulatory Precision	1	2	3	0.607	1.00

Variable	PostLSVT	PostMS	NP	Sig	χ^2
Loudness	2	0	4	0.135	4.00
Loudness Variability	1	0	**5***	0.030	7.00
Pitch	0	1	**5***	0.030	7.00
Pitch Variability	1	1	4	0.223	3.00
Closer to Normal Resonance	1	0	**5***	0.030	7.00
Voice Quality	0	1	**5***	0.030	7.00
Articulatory Precision	0	3	3	0.223	3.00
Variable	FuLSVT/PreMS	PostMS	NP	Sig	χ^2
Loudness	3	3	0	0.223	3.00
Loudness Variability	2	1	3	0.607	1.00
Pitch	1	1	4	0.223	3.00
Pitch Variability	2	1	3	0.607	1.00
Closer to Normal Resonance	3	0	3	0.223	3.00
Voice Quality	3	0	3	0.223	3.00
Articulatory Precision	4	2	0	0.135	4.00

Note. NP = no preference; Fu = follow-up; MS = Motor Speech; Sig = level of statistical significance; $\chi 2$ = chi squared value. The bold and asterisk value indicates the preference (PreLSVT, PostLSVT, FuLSVT/PreMS, PostMS) that was statistically significant.

Clinicians had no preference between: pre- and post-LSVT LOUD for pitch (χ^2 =12.00, p = 0.002), pitch variability (χ^2 = 7.00, p = 0.03), closer to normal resonance (χ^2 =12.00, p = 0.002), voice quality (χ^2 =12.00, p = 0.002), and articulatory precision (χ^2 = 7.00, p = 0.03); pre-LSVT LOUD and post-motor speech for pitch (χ^2 = 7.00, p = 0.03); post-LSVT LOUD and follow-up LSVT LOUD/pre motor speech for loudness variability (χ^2 =12.00, p = 0.002), pitch (χ^2 =12.00, p = 0.002), pitch variability (χ^2 = 7.00, p = 0.03), closer to normal resonance (χ^2 = 7.00, p = 0.03), and voice quality (χ^2 = 7.00, p = 0.03); and post-LSVT LOUD to post-motor speech for loudness variability (χ^2 = 7.00, p = 0.03), pitch (χ^2 = 7.00, p = 0.03), closer to normal resonance (χ^2 = 7.00, p = 0.03), and voice quality (χ^2 = 7.00, p = 0.03) indicating that there were no perceived changes in loudness variability, pitch, pitch variability, closer to normal resonance, voice quality, and articulatory precision, for lsvtf7, between the specified time points. All other preferences for voice and speech variables were not statistically significant for lsvtf7.

lsvtm9

At the time of initial testing lsvtm9, a thirteen-year-old male, had a diagnosis of mixed dysarthria and mild CAS. Increasing vocal loudness was his main target during LSVT LOUD treatment, and production of bilabial-velar, alveolar-velar and alveolar-alveolar sound patterns, and /t͡ʃ/ were his speech sound targets during motor speech treatment. Please refer to Table 2 and Table 3 for a more detailed description of the treatment schedule and repetition dose for LSVT LOUD and motor speech treatment, respectively.

Figure 8 depicts visual analyses for the variables dB SPL (A), intelligibility (B), nasalance scores (C), speaking rate (D), DDK performance (E), and proportion of consonant durations (F).

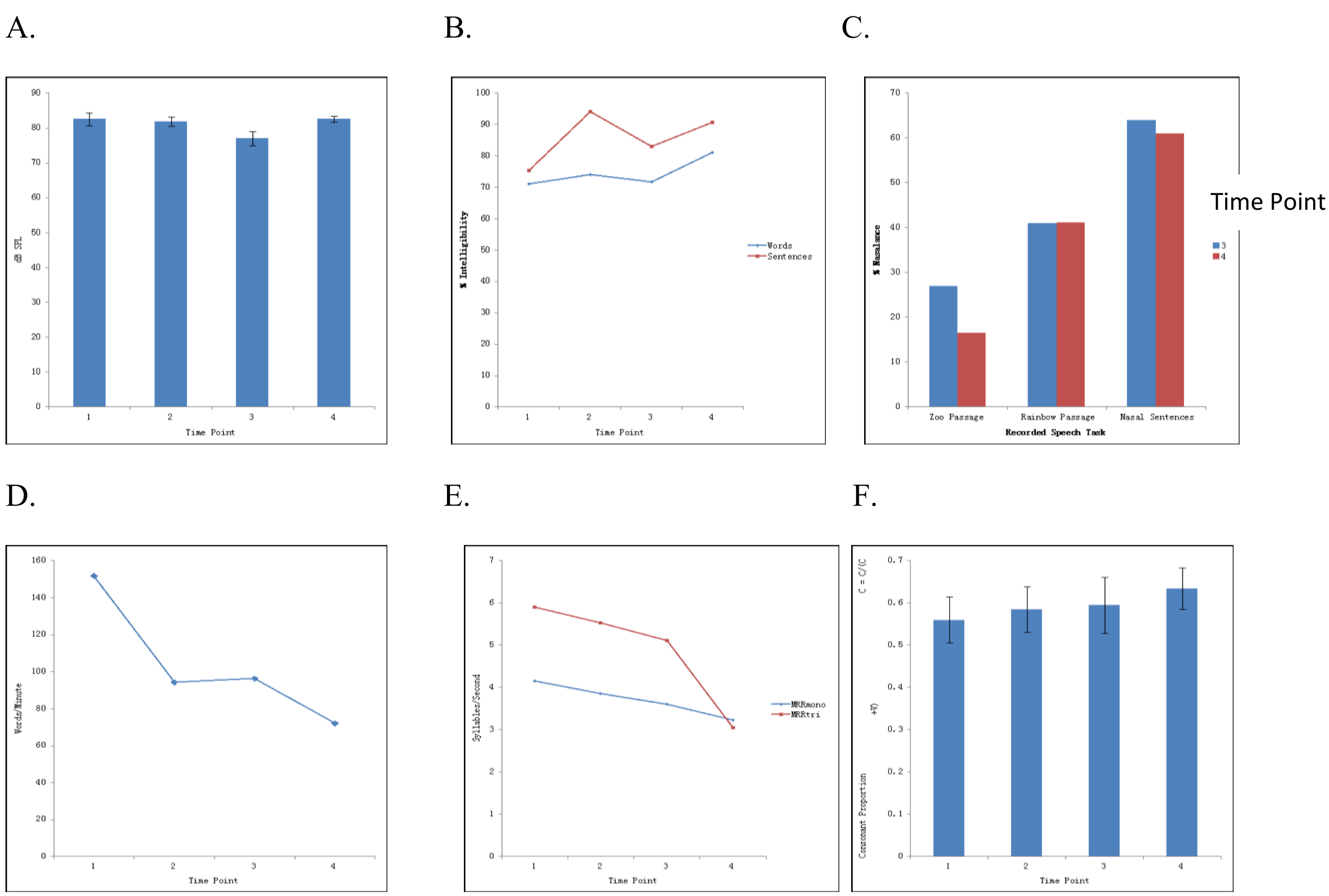


Figure 8. Visual analyses for lsvtm9 data, across all time points. Where A = Vocal Sound Levels (dB SPL, mouth-to-microphone distance = 10 cm), B = Percent Intelligibility, C = Nasalance Scores, D = Speaking Rate, E =DDKs, F = Consonant Proportions; and Time Point 1 = pre

LSVT LOUD, 2 = post LSVT LOUD, 3 = follow-up LSVT LOUD/pre motor speech, and 4 = post motor speech. Note: Time Points 2 and 4 are indicated by tic marks only on Panel B (Intelligibility).

Vocal Sound Level (dB SPL). Follow-up paired *t*-tests showed that vocal sound level (dB SPL) was significantly different between follow-up LSVT LOUD/pre motor speech and post-motor speech ($t = 9.209$, df = 8, $p < 0.0001$, one tailed).

Intelligibility. Follow-up paired *t*-tests showed that percent intelligibility for both words and sentences, were significantly different between: pre- and post-LSVT LOUD (sentences: $t = 3.020$, df = 3, $p = 0.03$, one tailed); pre-LSVT LOUD and follow-up LSVT LOUD/pre motor speech (sentences: $t = 2.409$, df = 3, $p = 0.05$, one tailed); pre-LSVT LOUD and post-motor speech (words: $t = 2.989$, df = 3, $p = 0.03$, one tailed; sentences: $t = 2.909$, df = 3, $p = 0.03$, one tailed); post-LSVT LOUD and post-motor speech (words: $t = 3.223$, df = 3, $p = 0.02$, one tailed); and follow-up LSVT LOUD/pre motor speech and post-motor speech (words: $t = 6.538$, df = 3, $p = 0.004$, one tailed; sentences: $t = 2.777$, df = 3, $p = 0.03$, one tailed).

Nasalance Scores. Percent nasalance stayed the same from follow-up LSVT LOUD/pre motor speech to post-motor speech, for the rainbow passage. However, there was a decrease in percent nasalance following motor speech treatment, for both the zoo passage and the nasal sentences task. Although there was a slight decrease in percent nasalance for nasal sentences, the values remained within one standard deviation of nasalance scores obtained from typical English speaking children. However, lsvtm9's percent naslance decreased for the zoo passage, falling within one standard deviation of normative values (Baken & Orlikoff, 2000).

Speaking Rate (WPM). lsvtm9 demonstrated a reduction in speaking rate following LSVT LOUD treatment. His speaking rate remained fairly constant at follow-up LSVT LOUD/pre motor speech, but decreased again following motor speech treatment. Overall, speaking rate decreased from approximately 150 WPM to 70 WPM.

DDKs. lsvtm9 demonstrated a reduction in his number of syllables per second (MRRmono and MRRtri) for both the AMR and SMR tasks, across all four time points. The lowest number of syllables was observed following motor speech treatment.

Proportion of Consonant Durations. A follow-up paired *t*-test showed that the consonant proportions were significantly larger pre-LSVT LOUD to follow-up LSVT LOUD/pre motor speech ($t = 2.260$, df = 7, $p = 0.06$, two tailed) and pre-LSVT LOUD to post-motor speech ($t = 2.423$, df = 7, $p = 0.05$, two tailed). A Pearson's correlation revealed a significant positive correlation between intelligibility for words and consonant proportion ($r = 0.903$, N = 4, $p = 0.0485$, one tailed). Additionally, a Pearson's correlation showed a significant negative correlation between speaking rate and consonant proportion ($r = -0.898$, N = 4, $p = 0.05$, one tailed), suggesting that as lsvtm9 slowed his speaking rate, his consonant proportion became longer in duration.

Vowel Space. Figure 9 shows formant frequency values for the corner vowels /i/, /ɑ/, and /u/, across all time points for lsvtm9, as well as normative data for typically developing children. Following motor speech treatment, lsvtm9 displayed formant frequencies that resemble back vowels in typically developing speech, as illustrated by a decrease in F2 for /u/ and an increase in F1 for /ɑ/. However, an increase in F1 for /u/ and a decrease in F2 for /i/ illustrate formant frequencies that deviate from that of typically developing children, suggesting that tongue position for front vowels was slightly compromised.

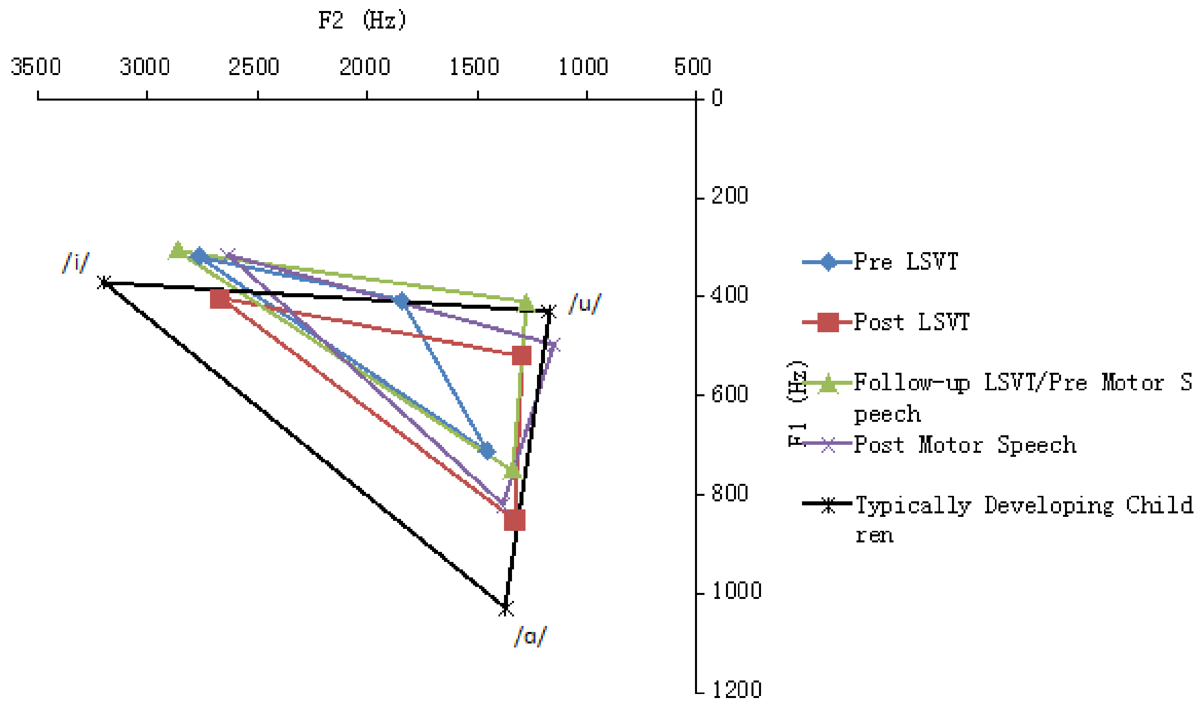


Figure 9. Corner vowel formant frequencies across all time points for lsvtm9, and normative data for typically developing children. Formant frequency values for the corner vowels /i/, /ɑ/, and /u/, across all time points depicted in different colors (pre-LSVT LOUD = blue; post-LSVT LOUD = red; follow-up LSVT LOUD/Pre-Motor Speech Tx = green; Post-Motor Speech Tx = purple) against the normative data for typically developing children of the same age range depicted in black.

Listener Perception. Table 8 shows a summary of the Chi-square analyses for clinician preference on perceptual variables of voice and speech, for lsvtm9, across all four time points.

Table 8. *Summary Chi-square statistics for lsvtm9 on clinician preference for voice and speech produced on un-trained sentences pre- LSVT-, post- LSVT, follow-up LSVT/pre Motor Speech and post Motor Speech.*

Variable	PreLSVT	PostLSVT	NP	Sig	χ^2
Loudness	0	**5***	1	0.030	7.00
Loudness Variability	0	3	3	0.223	3.00
Pitch	0	3	3	0.223	3.00
Pitch Variability	0	4	2	0.135	4.00
Closer to Normal Resonance	0	2	4	0.135	4.00
Voice Quality	0	4	2	0.135	4.00
Articulatory Precision	0	3	3	0.223	3.00

Variable	PreLSVT	FuLSVT/PreMS	NP	Sig	χ^2
Loudness	1	2	3	0.607	1.00
Loudness Variability	1	0	**5***	0.030	7.00
Pitch	2	1	3	0.607	1.00
Pitch Variability	3	1	2	0.607	1.00
Closer to Normal Resonance	2	1	3	0.607	1.00
Voice Quality	1	1	4	0.223	3.00
Articulatory Precision	2	1	3	0.607	1.00
Variable	PreLSVT	PostMS	NP	Sig	χ^2
Loudness	1	**5***	0	0.030	7.00
Loudness Variability	1	2	3	0.607	1.00
Pitch	2	1	3	0.607	1.00
Pitch Variability	2	1	3	0.607	1.00
Closer to Normal Resonance	3	1	2	0.607	1.00
Voice Quality	3	2	1	0.607	1.00
Articulatory Precision	2	1	3	0.607	1.00
Variable	PostLSVT	FuLSVT/PreMS	NP	Sig	χ^2
Loudness	**6***	0	0	0.002	12.0
Loudness Variability	**5***	0	1	0.030	7.00
Pitch	3	0	3	0.223	3.00
Pitch Variability	**5***	0	1	0.030	7.00
Closer to Normal Resonance	3	0	3	0.223	3.00
Voice Quality	4	0	2	0.135	4.00
Articulatory Precision	4	0	2	0.135	4.00
Variable	PostLSVT	PostMS	NP	Sig	χ^2
Loudness	4	0	2	0.135	4.00
Loudness Variability	**5***	0	1	0.030	7.00
Pitch	3	0	3	0.223	3.00
Pitch Variability	**5***	0	1	0.030	7.00
Closer to Normal Resonance	3	0	3	0.223	3.00
Voice Quality	**5***	0	1	0.030	7.00
Articulatory Precision	2	0	4	0.135	4.00
Variable	FuLSVT/PreMS	PostMS	NP	Sig	χ^2
Loudness	0	4	2	0.135	4.00
Loudness Variability	2	1	3	0.607	1.00
Pitch	1	1	4	0.223	3.00
Pitch Variability	3	1	2	0.607	1.00
Closer to Normal Resonance	2	1	3	0.607	1.00
Voice Quality	2	2	2	1.000	0.00
Articulatory Precision	0	1	**5***	0.030	7.00

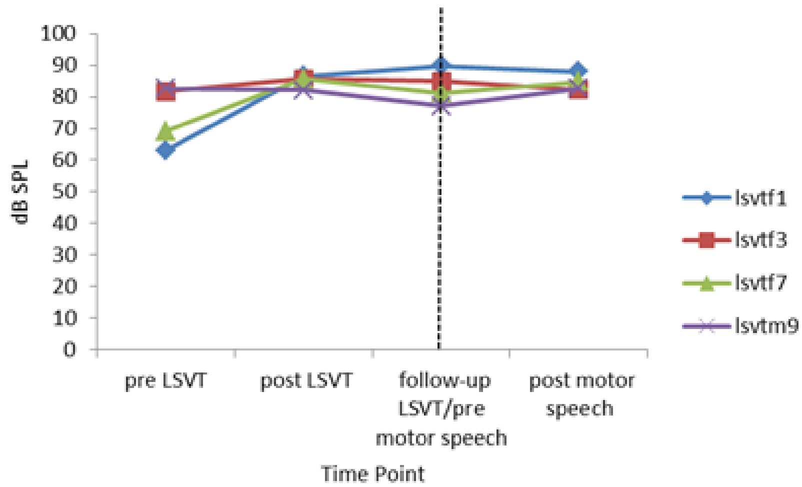
Note. NP = no preference; Fu = follow-up; MS = Motor Speech; Sig = level of statistical significance; $\chi 2$ = chi squared value. The bold and asterisk value indicates the preference (PreLSVT, PostLSVT, FuLSVT/PreMS, PostMS) that was statistically significant.

Preference for loudness post-treatment was statistically significant for pre- and post-LSVT LOUD ($\chi^2 = 7.00$, $p = 0.03$) and pre-LSVT LOUD and post-motor speech ($\chi^2 = 7.00$, $p = 0.03$).

Preference for perceptual variables post-LSVT LOUD treatment were statistically significant for post-LSVT LOUD and follow-up LSVT LOUD/pre motor speech for loudness (χ^2 =12.00, p = 0.002), loudness variability (χ^2 = 7.00, p = 0.03), and pitch variability (χ^2 = 7.00, p = 0.03); post-LSVT LOUD and post-motor speech for loudness variability (χ^2 = 7.00, p = 0.03), pitch variability (χ^2 = 7.00, p = 0.03), and voice quality (χ^2 = 7.00, p = 0.03). Clinicians had no preference between: pre-LSVT LOUD and follow-up LSVT LOUD/pre motor speech for loudness variability (χ^2 = 7.00, p = 0.03); and follow-up LSVT LOUD/pre motor speech and post-motor speech for articulatory precision (χ^2 = 7.00, p = 0.03) indicating that there were no perceived changes in loudness variability and articulatory precision, for lsvtm9, between the specified time points. All other preferences for voice and speech variables were not statistically significant for lsvtm9.

Summary

Vocal Sound Level (dB SPL). Figure 10 shows summary data for vocal sound level across all time points and participants. Three of the four participants demonstrated statistically significant increases in dB SPL following LSVT LOUD. The same three participants were able to maintain or further improve on those gains at 12-weeks follow-up. Two of the four participants showed increased dB SPL post-motor speech compared to pre-treatment measures and two of the four participants demonstrated additional gains in vocal sound level following the motor speech treatment alone.

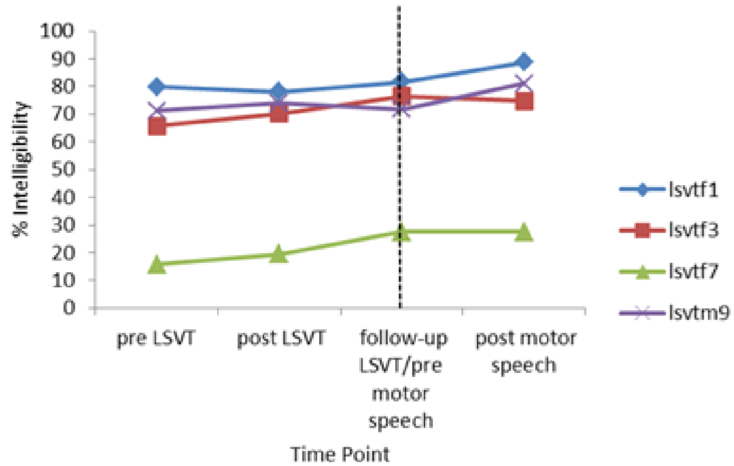


Participant	Pre vs. Post	Pre vs. FUP	Post vs. FUP	Pre vs. PostM	Post vs. PostM	FUP vs PostM
lsvtf1	↑*	↑*	↑*	↑*	↑*	↓*
lsvtf3	↑*	↑*	↓*	__	↓*	↓*
lsvtf7	↑*	↑*	↓*	↑*	__	↑*
lsvtm9	__	↓*	↓*	__	__	↑*

Figure 10. Summary Data for Vocal Sound Level. dB SPL across all time points and participants, depicted in different colors (lsvtf1 = blue; lsvtf3 = red; lsvtf7 = green; lsvtm9 = purple). Where dotted line = separation between LSVT LOUD and motor speech treatment; Pre = pre-LSVT LOUD; Post = post-LSVT LOUD; FUP = follow-up LSVT LOUD/pre motor speech; PostM = post-motor speech; asterisked value indicates a statistically significant change; superscript t value indicates a trend; − indicates no change.

Intelligibility. Figures 11 and 12 show summary data for percent intelligibility across all time points and participants for both words and sentences, respectively. Three of the four participants displayed a trend of increasing percent intelligibility for words following LSVT LOUD, with two participants showing significantly increased percent intelligibility at 12-weeks follow-up compared to pre-treatment measures. All four participants demonstrated a significant increase in percent intelligibility following motor speech treatment compared to the beginning of the study, with two of the four participants showing additional gains in intelligibility following the motor speech treatment

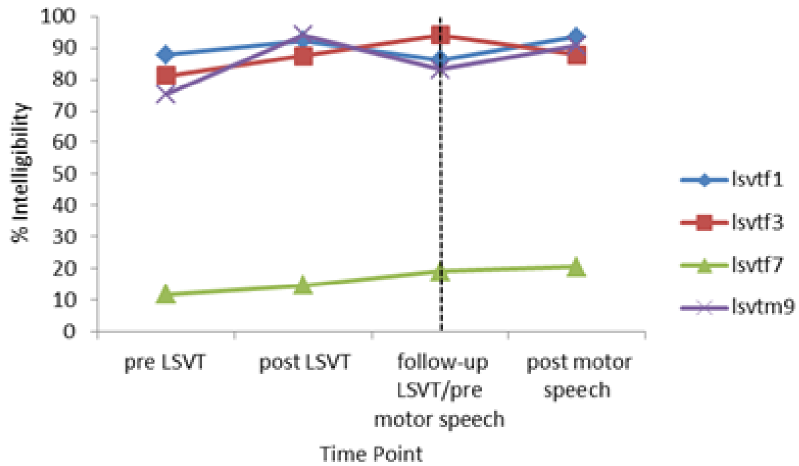
alone.



Participant	Pre vs. Post	Pre vs. FUP	Post vs. FUP	Pre vs. PostM	Post vs. PostM	FUP vs PostM
lsvtf1	—	—	$\uparrow^{t}$	$\uparrow^{*}$	$\uparrow^{*}$	$\uparrow^{*}$
lsvtf3	$\uparrow^{t}$	$\uparrow^{*}$	$\uparrow^{t}$	$\uparrow^{*}$	$\uparrow^{t}$	$\downarrow^{t}$
lsvtf7	$\uparrow^{t}$	$\uparrow^{*}$	$\uparrow^{t}$	$\uparrow^{*}$	$\uparrow^{t}$	—
lsvtm9	$\uparrow^{t}$	—	$\downarrow^{t}$	$\uparrow^{*}$	$\uparrow^{*}$	$\uparrow^{*}$

Figure 11. Summary Data for Intelligibility (Words). Percent intelligibility across all time points and participants, depicted in different colors (lsvtf1 = blue; lsvtf3 = red; lsvtf7 = green; lsvtm9 = purple). Where dotted line = separation between LSVT LOUD and motor speech treatment; Pre = pre-LSVT LOUD; Post = post-LSVT LOUD; FUP = follow-up LSVT LOUD/pre motor speech; PostM = post-motor speech; asterisked value indicates a statistically significant change; superscript t value indicates a trend; − indicates no change.

All four participants displayed a trend of increasing percent intelligibility for sentences following LSVT LOUD. Three of the four participants showed a visual trend indicating that they were able to maintain or further improve on those gains at 12-weeks follow-up. All four participants demonstrated a significant increase in percent intelligibility following motor speech treatment compared to the beginning of the study, with two of the four participants showing additional gains in intelligibility following the motor speech treatment on its own.



Participant	Pre vs. Post	Pre vs. FUP	Post vs. FUP	Pre vs. PostM	Post vs. PostM	FUP vs PostM
lsvtf1	↑^{t}	—	↓^{t}	↑*	—	↑*
lsvtf3	↑*	↑*	↑*	↑*	—	↓^{t}
lsvtf7	↑^{t}	↑^{t}	↑^{t}	↑*	↑^{t}	—
lsvtm9	↑*	↑*	↓*	↑*	↑^{t}	↑*

Figure 12. Summary Data for Intelligibility (Sentences). Percent intelligibility across all time points and participants, depicted in different colors (lsvtf1 = blue; lsvtf3 = red; lsvtf7 = green; lsvtm9 = purple). Where dotted line = separation between LSVT LOUD and motor speech treatment; Pre = pre-LSVT LOUD; Post = post-LSVT LOUD; FUP = follow-up LSVT LOUD/pre motor speech; PostM = post-motor speech; asterisked value indicates a statistically significant change; superscript t value indicates a trend; − indicates no change.

Nasalance Scores. Figure 13, 14 and 15 show summary Data for percent nasalance, pre- and post-motor speech, across all participants for the zoo passage, rainbow passage, and nasal sentences, respectively.

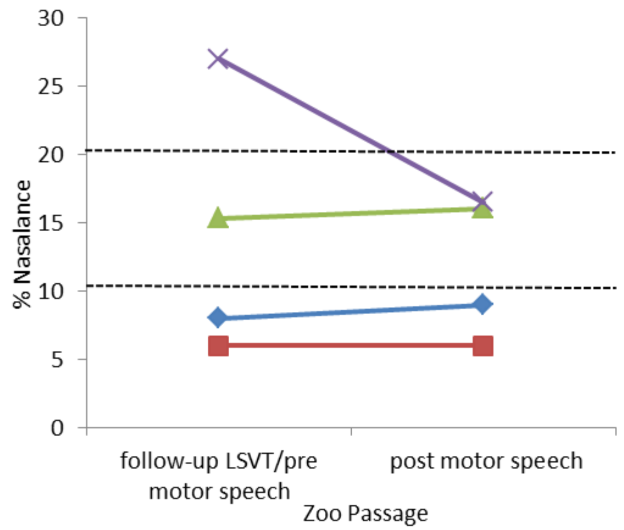


Figure 13. Summary Data for Zoo Passage. Percent nasalance, pre- and post-motor speech, across all participants, depicted in different colors (lsvtf1 = blue; lsvtf3 = red; lsvtf7 = green; lsvtm9 = purple). Where dotted line = normative range for typically developing children.

One participant demonstrated a reduction in percent nasalance, for the zoo passage, resulting in a score that fell within the range of normal for typically developing speech, while a second participant displayed an increase in percent nasalance, resulting in a score that approached the normative range. The other two participants did not demonstrate a notable change in percent nasalance for this speech task.

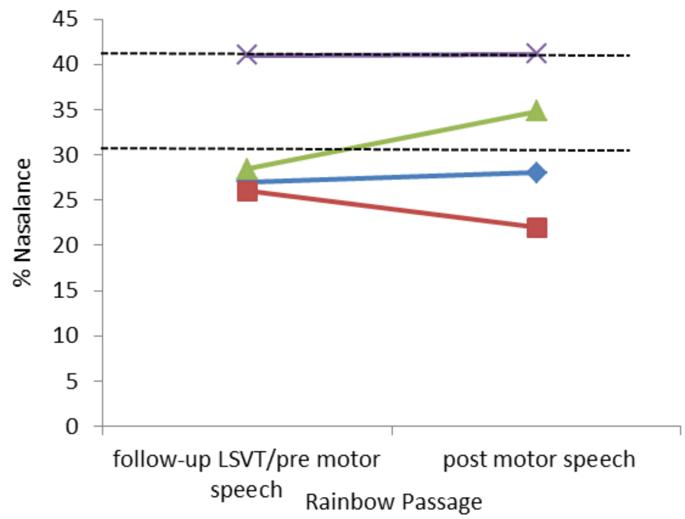


Figure 14. Summary Data for Rainbow Passage. Percent nasalance, pre- and post-motor speech, across all participants, depicted in different colors (lsvtf1 = blue; lsvtf3 = red; lsvtf7 = green; lsvtm9 = purple). Where dotted line = normative range for typically developing children.

One participant demonstrated an increase in percent nasalance, for the rainbow passage, resulting in a score that fell within the range of normal for typically developing speech, while a second participant displayed an increase in percent nasalance, resulting in a score that approached the normative range.

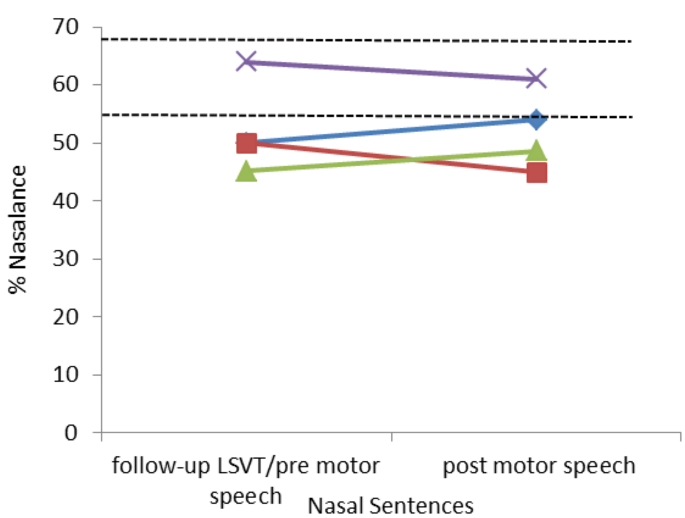
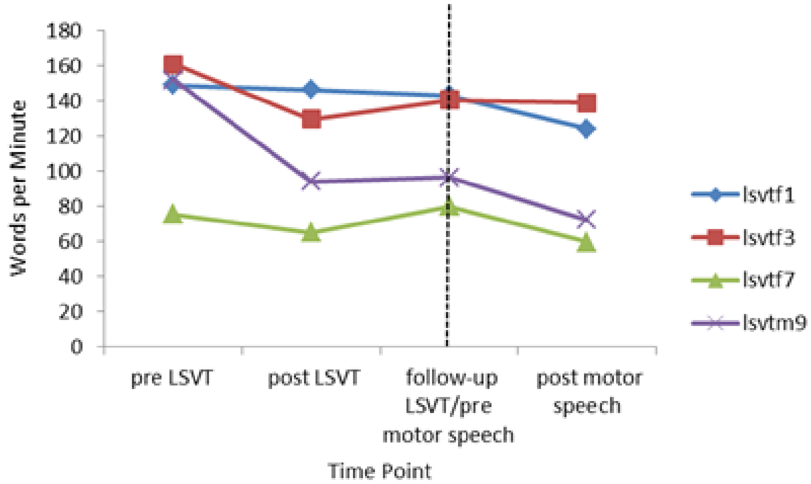


Figure 15. Summary Data for Nasal Sentences. Percent nasalance, pre- and post-motor speech, across all participants, depicted in different colors *(*lsvtf1 = blue; lsvtf3 = red; lsvtf7 = green; lsvtm9 = purple). Where dotted line = normative range for typically developing children.

One participant demonstrated an increase in percent nasalance, for the nasal sentences, resulting in a score that fell within the range of normal for typically developing speech, while a second participant displayed an increase in percent nasalance, resulting in a score that approached the normative range.

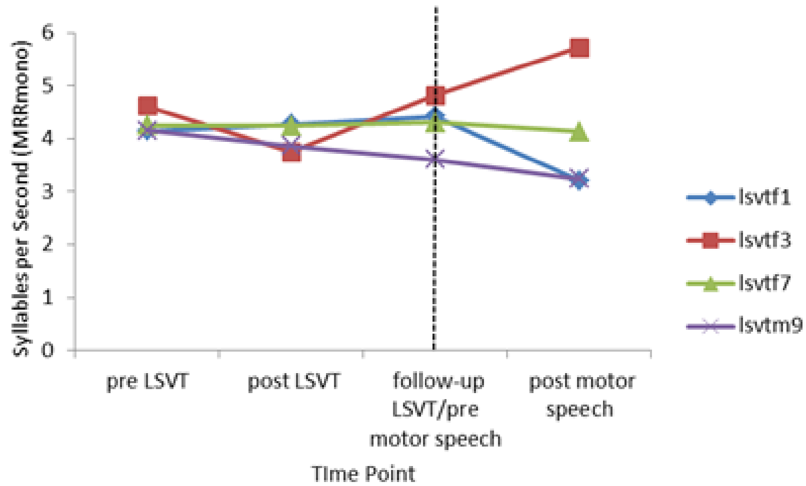
Speaking Rate. Figure 16 shows summary data for speaking rate across all time points and participants. All four participants displayed a trend of decreased speaking rate following LSVT LOUD. Three of the four participants were able to maintain or further decreased speaking rate at 12-weeks follow-up. All four participants demonstrated a decrease in speaking rate following motor speech treatment compared to the beginning of the study, with three of the four participants showing additional reductions in speaking rate following the motor speech treatment on its own.



Participant	Pre vs. Post	Pre vs. FUP	Post vs. FUP	Pre vs. PostM	Post vs. PostM	FUP vs PostM
lsvtf1	↓^{t}	↓^{t}	↓^{t}	↓^{t}	↓^{t}	↓^{t}
lsvtf3	↓^{t}	↓^{t}	↑^{t}	↓^{t}	↑^{t}	—
lsvtf7	↓^{t}	↑^{t}	↑^{t}	↓^{t}	↓^{t}	↓^{t}
lsvtm9	↓^{t}	↓^{t}	—	↓^{t}	↓^{t}	↓^{t}

Figure 16. Summary Data for Speaking Rate. Words per minute across all time points and participants, depicted in different colors (lsvtf1 = blue; lsvtf3 = red; lsvtf7 = green; lsvtm9 = purple). Where dotted line = separation between LSVT LOUD and motor speech treatment; Pre = pre-LSVT LOUD; Post = post-LSVT LOUD; FUP = follow-up LSVT LOUD/pre motor speech; PostM = post-motor speech; asterisked value indicates a statistically significant change; superscript t value indicates a trend; − indicates no change.

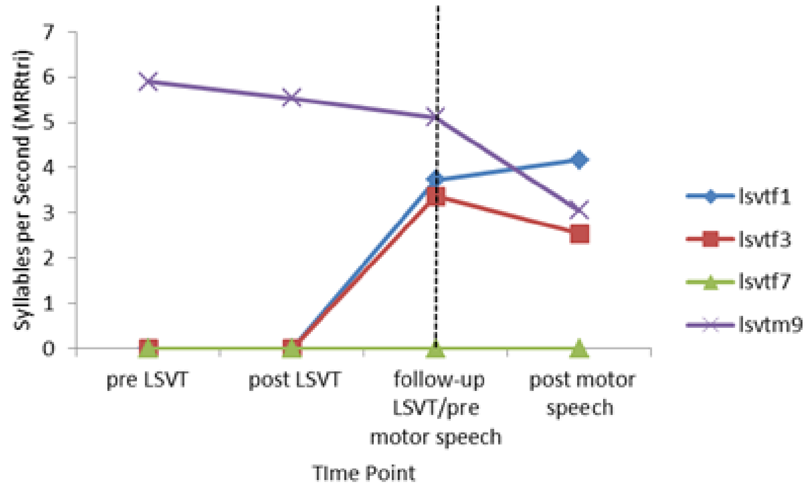
DDKs. Figures 17 and 18 show summary Data for DDKs across all time points and participants for both MRRmono and MRRtri, respectively. Two of four participants displayed a trend of decreased monosyllabic repetition rate following LSVT LOUD, with one participant demonstrating a continued reduction at 12-weeks follow-up. Three of the four participants demonstrated a decrease in monosyllabic repetition rate following motor speech treatment compared to the beginning of the study, each displaying additional reductions following the motor speech treatment alone.



Participant	Pre vs. Post	Pre vs. FUP	Post vs. FUP	Pre vs. PostM	Post vs. PostM	FUP vs PostM
lsvtf1	↑^{t}	↑^{t}	↑^{t}	↓^{t}	↓^{t}	↓^{t}
lsvtf3	↓^{t}	↑^{t}	↑^{t}	↑^{t}	↑^{t}	↑^{t}
lsvtf7	—	—	—	↓^{t}	↓^{t}	↓^{t}
lsvtm9	↓^{t}	↓^{t}	↓^{t}	↓^{t}	↓^{t}	↓^{t}

Figure 17. Summary Data for DDKs (MRRmono). Monosyllabic repetition rates in syllables per second across all time points and participants, depicted in different colors (lsvtf1 = blue; lsvtf3 = red; lsvtf7 = green; lsvtm9 = purple). Where dotted line = separation between LSVT LOUD and motor speech treatment; Pre = pre-LSVT LOUD; Post = post-LSVT LOUD; FUP = follow-up LSVT LOUD/pre motor speech; PostM = post-motor speech; asterisked value indicates a statistically significant change; superscript t value indicates a trend; − indicates no change.

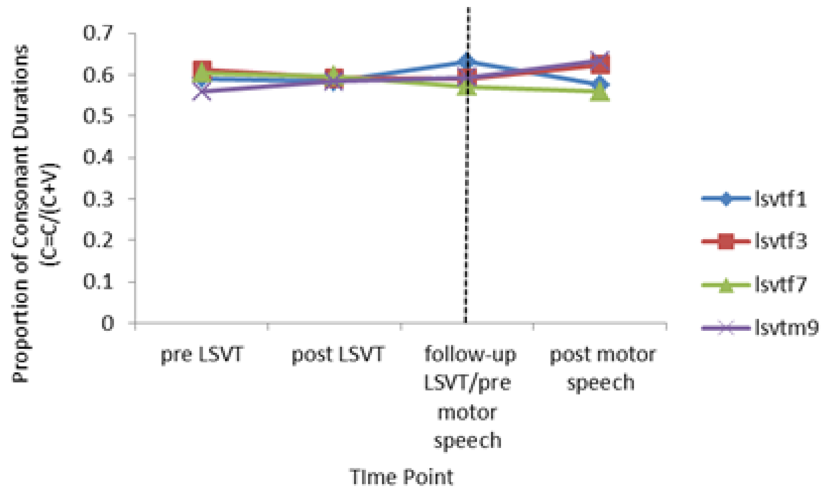
One participant displayed a trend of decreased trisyllabic repetition rate following LSVT LOUD, while three participants were unable to correctly produce a trisyllabic sequence at both pre- and post- LSVT LOUD. Two of these three participants were able to successfully complete the task at 12-weeks follow-up. Two of the three participants who were able to compete the task by the end of the study, displayed a reduction in trisyllabic repetition rate following the motor speech treatment alone.



Participant	Pre vs. Post	Pre vs. FUP	Post vs. FUP	Pre vs. PostM	Post vs. PostM	FUP vs PostM
lsvtf1	—	$\uparrow^{t}$	$\uparrow^{t}$	$\uparrow^{t}$	$\uparrow^{t}$	$\uparrow^{t}$
lsvtf3	—	$\uparrow^{t}$	$\uparrow^{t}$	$\uparrow^{t}$	$\uparrow^{t}$	$\downarrow^{t}$
lsvtf7	—	—	—	—	—	—
lsvtm9	$\downarrow^{t}$	$\downarrow^{t}$	$\downarrow^{t}$	$\downarrow^{t}$	$\downarrow^{t}$	$\downarrow^{t}$

Figure 18. Summary Data for DDKs (MRRtri). Trisyllabic repetition rates in syllables per second across all time points and participants, depicted in different colors *(*lsvtf1 = blue; lsvtf3 = red; lsvtf7 = green; lsvtm9 = purple). Where dotted line = separation between LSVT LOUD and motor speech treatment; Pre = pre-LSVT LOUD; Post = post-LSVT LOUD; FUP = follow-up LSVT LOUD/pre motor speech; PostM = post-motor speech; asterisked value indicates a statistically significant change; superscript t value indicates a trend; − indicates no change.

Proportion of Consonant Durations. Figure 19 shows summary data for proportion of consonant durations across all time points and participants. Two opposing trends were observed, with half the participants showing shortened consonant proportion durations and the other half displaying lengthened consonant proportion durations, following motor speech treatment compared to the beginning of the study.



Participant	Pre vs. Post	Pre vs. FUP	Post vs. FUP	Pre vs. PostM	Post vs. PostM	FUP vs PostM
lsvtf1	$\downarrow^{t}$	$\uparrow^{t}$	$\uparrow^{t}$	$\downarrow^{t}$	$\downarrow^{t}$	↓*
lsvtf3	$\downarrow^{t}$	$\downarrow^{t}$	—	$\uparrow^{t}$	↑*	$\uparrow^{t}$
lsvtf7	$\downarrow^{t}$	$\downarrow^{t}$	$\downarrow^{t}$	$\downarrow^{t}$	$\downarrow^{t}$	$\downarrow^{t}$
lsvtm9	—	$\uparrow^{t}$	—	↑*	$\uparrow^{t}$	—

Figure 19. Summary Data for Proportion of Consonant Durations. Proportion of consonant durations across all time points and participants, depicted in different colors (lsvtf1 = blue; lsvtf3 = red; lsvtf7 = green; lsvtm9 = purple). Where dotted line = separation between LSVT LOUD and motor speech treatment; Pre = pre-LSVT LOUD; Post = post-LSVT LOUD; FUP = follow-up LSVT LOUD/pre motor speech; PostM = post-motor speech; asterisked value indicates a statistically significant change; superscript t value indicates a trend; − indicates no change.

Vowel Space. Table 9 shows summary data for formant frequency values for the corner vowels /i/, /ɑ/, and /u/, across all four participants. Two of the four participants demonstrated initial gains in first formant frequency values following LSVT LOUD, with all four participants displaying additional gains post-motor speech compared to pre-treatment measures. Similarly, three of the four participants showed initial gains in second formant frequency values following LSVT LOUD, with all four participants demonstrating additional gains following motor speech treatment compared to the beginning of the study.

Table 9. *Formant Frequency values for the corner vowels /i/, /a/, and /u/, across all four participants, depicted in different colors (lsvtf1 = blue; lsvtf3 = red; lsvtf7 = green; lsvtm9 = purple).*

Vowel	pre-LSVT vs. post-LSVT	pre-LSVT vs. post-motor speech
Participants Whose F1 Values Approached those of TDC		
/i/	lsvtm9	lsvtf3, lsvtf7
/u/	—	lsvtf3, lsvtf7
/ɑ/	lsvtf7, lsvtm9	lsvtf1, lsvtf7, lsvtm9
Participants Whose F2 Values Approached those of TDC		
/i/	lsvtf3	lsvtf3, lsvtf7
/u/	lsvtf7, lsvtm9	lsvtf1, lsvtf3, lsvtf7, lsvtm9
/ɑ/	lsvtf3, lsvtm9	lsvtf3, lsvtm9

Note. F1 = first formant frequency; TDC = typically developing children; F2 = second formant frequency.

Discussion

LSVT LOUD targeting vocal loudness followed by a motor speech treatment targeting articulation and speech motor sequencing was used to provide a sequential treatment approach for children with mixed diagnoses of dysarthria and CAS secondary to CP. This is the first study to combine LSVT LOUD treatment sequentially with a motor speech treatment for this population. All participants showed positive changes in at least one dependent variable following LSVT LOUD and continued improvement on the same or additional independent variables following motor speech treatment.

LSVT LOUD Treatment

The target of LSVT LOUD was vocal loudness. The high intensity delivery and neural plasticity promoting principles of LSVT LOUD make it an effective training approach for vocal loudness, resulting in improvements across all areas of the speech production mechanism (Fox et al., 2006). Depending on the voice profile of each participant, the target was to either increase vocal loudness or to enhance loudness modulation in the healthy range (see Table 1). The LSVT LOUD treatment consisted of 16 hours of individual 1-hour treatment sessions over a 4-week time period, which included additional structured homework and carryover exercises follow by a 12-week maintenance program (see Table 2).

Vocal Sound Level (dB SPL). lsvtf1, lsvtf3, and lsvtf7 displayed significantly higher dB SPL values on untrained phrases following LSVT LOUD treatment. At 12-weeks follow-up LSVT LOUD these same three participants demonstrated dB SPL values that were significantly higher than values obtained prior to treatment. These changes suggest that specificity of training in vocal loudness was internally calibrated by these three participants and carried over to untrained sentences outside of the treatment setting. These findings are consistent with those of Fox and Boliek (2012; 2014) who reported significant increases in dB SPL for children with dysarthria secondary to CP on a sentence repetition task, following LSVT LOUD treatment and again at 6- or 8-weeks follow-up. These findings also are consistent with those of Levy and colleagues (Levy et al., 2013) who found increases in dB SPL following LSVT in a similar clinical group. One of four participants (lsvtm9) did not demonstrate a significant change in dB SPL following LSVT LOUD treatment for untrained sentence productions. At 12-weeks follow-up lsvtm9's vocal sound level had significantly decreased compared to pre-treatment measures. Unlike the other three participants, lsvtm9 was the only child who presented with a weakened respiratory system and an ataxic type dysarthria making it physically more difficult to produce speech in the range of healthy vocal loudness. In this case, a single dose of LSVT LOUD may not have been enough to increase strength and endurance or to have established an internal recalibration of healthy vocal loudness. To address the calibration issue, it would be necessary to examine the vocal SPL on trained tasks such as sustained phonation and functional phrases, which were practiced daily throughout the treatment and maintenance phases of treatment.

Training of vocal loudness is thought to result in improvements across all areas of the speech production mechanism, and speech gains are thought to generalize to functional communication (Fox et al., 2006; Pennington et al., 2009; Pennington et al., 2013). For this reason, it was expected that additional gains in intelligibility, listener preference for treated voices, and speech acoustic variables would be observed following LSVT LOUD.

Intelligibility. A visual trend illustrated an increase in percent intelligibility for untrained sentences following LSVT LOUD for all four children, although this increase was only significant for lsvtf3 and lsvtm9. At 12-weeks follow-up, all four children showed a significant increase in percent intelligibility compared to pre-treatment measures. These findings are consistent with those of Pennington and colleagues (2009; 2013) who reported that unfamiliar listeners understood significantly more single words and words in connected speech of children with dysarthria secondary to CP, following a treatment that targeted body functions of respiration, phonation, and speech rate. These results also are consistent with those of Levy and colleagues (Levy et al., 2013) who reported increases in intelligibility following LSVT LOUD, in children who have diagnoses of dysarthria and CP.

Listener Perception. Listeners showed significant preference for perceptual variables for both lsvtf3 and lsvtm9. Listeners preferred articulatory precision for lsvtf3 at post-LSVT LOUD and follow-up LSVT LOUD/pre motor speech compared to pre-treatment, indicating that listeners perceived an improvement in meeting articulatory targets immediately following treatment as well as after the maintenance program thus, indicating some skill stability. Listeners preferred overall loudness for lsvtm9 at post-LSVT LOUD compared to pre-treatment and follow-up measures, suggesting that perceived gains in loudness made during LSVT LOUD were not maintained 12-weeks following treatment. Additionally, listeners preferred loudness and pitch variability for lsvtm9 at post-LSVT LOUD compared to measures obtained at follow-up LSVT LOUD/pre motor speech and post-motor speech.

Results for lsvtf3 are consistent with Boliek and Fox (2014) who reported perceived improvements in articulatory precision for one of two children immediately following LSVT LOUD. Both children in that case report continued to make gains in vocal loudness following an 8-week maintenance program. However, Fox and Boliek (2012) reported additional perceptual improvements in overall loudness, loudness variability, pitch variability, and overall voice quality following LSVT LOUD for three out of four children in that study, which were not observed in the present study. There are several possible reasons for the discrepancy in findings across studies. First, previous studies (Boliek & Fox 2014; Fox & Boliek, 2012; Levy et al., 2013) only included children with spastic-type dysarthria having voice profiles indicating strained-strangled, breathy, or variable voice quality. The voice profiles of participants in the present study may have been different from those in previous studies. None of these participants were characterized as having a strained-strangled voice quality and only lsvtm9 was characterized as having a consistent breathy voice quality. Therefore it stands to reason that preference for loudness post-LSVT LOUD would align with lsvtm9 and preference for improved articulatory precision following LSVT LOUD aligns with the profile of lsvtf3. However, to explain a lack of findings for the other participants, other factors should be considered. For example, unlike Fox and Boliek (2012) whose protocol allowed listeners to replay each sample as many times as needed to make a decision, listeners in the present study were instructed to only listen to each paired sample one time prior to making a decision as to resemble daily communicative interactions. This may have impacted the listeners' ability to make an informed choice, resulting in a large number of 'no preference' responses.

Speaking Rate (WPM). Participants' lsvtf3, lsvtf7, and lsvtm9 demonstrated a reduction in speaking rate following LSVT LOUD and again at 12-weeks follow-up. Participant lsvtf1 showed a reduction in speaking rate following motor speech treatment. Previous literature has shown that children with dysarthria and CP have slower speaking rates compared to children with typically developing speech (Hodge & Gotzke, 2014; Chen et al., 2012). However, when looking at intelligibility as a by-product of speaking rate, children with dysarthria and CP have lower intelligibility scores when speaking rate is faster and higher intelligibility scores when speaking rate is slower (Chen et al., 2012). Results from the present study conform to the work of Chen and colleagues (Chen et al., 2012), in that all four children displayed an increase in percent intelligibility following treatment and a corresponding decline in speaking rate.

DDKs. lsvtf3 and lsvtm9 displayed slower MRRmono rates on an AMR task following LSVT LOUD treatment compared to their pre-treatment rates. Although children with CAS have been found to produce slow and variable scores on AMR tasks (Rvachew et al., 2005; Terband et al., 2009), the detected reduction in speaking rate over time corresponds to the observed reduction in syllables per second for these children (see Appendix A). Likewise, lsvtm9 demonstrated a similar trend of slower MRRtri rates on the SMR task following LSVT LOUD. Consistent with work by Rvachew et al., (2005) and Terband et al., (2009), lsvtf1 and lsvtf3 were unable to produce a correct tri-syllabic sequence on the SMR task pre-LSVT LOUD. Both participants were able to successfully produce correct tri-syllabic sequences by the end of the 12-week maintenance program and following motor speech training. The acquisition of this skill may be related to motor learning principles (intensive practice with multiple repetitions, and increased complexity) as described in the activity-dependent neuroplasticity literature (Schertz & Gorden, 2008; Kleim & Jones, 2008; Ludlow et al., 2008).

Vowel Space. Following LSVT LOUD, lsvtf3 and lsvtm9 produced F1 values for /i/ that moved closer to formant frequency values observed in speech by typically developing children (Peterson & Barney, 1952). Similarly, lsvtf7 and lsvtm9 showed increased F1 values for /ɑ/ following LSVT LOUD treatment, resulting in formant frequencies that approach those reported in pediatric norms (Peterson & Barney, 1952). These results are consistent with Chen and colleagues (2012) who documented a limited F1 range in children with CP, accounted for by F1 values that are higher in high vowels such as /i/, and F1 values that are lower in low vowels such as /ɑ/. Because F1 corresponds with tongue height (Chen et al., 2012), F1 values that were found to more closely resemble those of pediatric normative values, suggests tongue height positioning, improved following LSVT LOUD for the participants in the present study. F2 frequency values lowered for both /i/ (in the cases of lsvtf1, lsvtf7, and lsvtm9) and /u/ (in the cases of lsvtf3, lsvtf7 and lsvtm9) following LSVT LOUD treatment, resulting in F2 values for /i/ that moved away from normative values and F2 values for /u/ that moved in the direction of normative values. The observed lowering of F2 for /u/ is consistent with reported findings by Sapir and colleagues (Sapir et al., 2007) indicating lowered F2 for /u/ in adults with dysarthria, following LSVT LOUD. However, the findings for F2 values for /i/ are inconsistent with Sapir and colleagues (Sapir et al., 2007) who reported heightened F2 values for /i/ following LSVT LOUD in these same adults. F2 value alterations observed in the present study may indicate an increase in range of tongue movements, specifically in the front to back direction (Sapir et al., 2007) for some vowels but not others.

Motor Speech Treatment.

The target of motor speech treatment was articulation and speech motor sequencing with treatment targets and repetition dosage identified for each participant (see Tables 1 and 3). Pennington and colleagues (Pennington et al., 2009) suggest that a multi-system treatment approach, targeting respiration, phonation, resonance, and articulation, is recommended for this population. Because problems with articulatory precision are often a result of the respiratory, phonatory and resonance subsystems, treatment of articulation is recommended to come after initial treatment of the other affected subsystems (Pennington et al., 2009). Therefore, additional speech gains were expected following the motor speech treatment block.

Vocal Sound Level (dB SPL). lsvtf7 and lsvtm9 both displayed increases in dB SPL values on untrained phrases from follow-up LSVT LOUD/pre motor speech to post-motor speech. These two participants made additional gains in vocal loudness following motor speech treatment. In contrast, lsvtf1 and lsvtf3 both showed reductions in dB SPL from follow-up LSVT LOUD/pre motor speech to post-motor speech. However, all four children showed significantly higher dB SPL values from pre-LSVT LOUD to post-motor speech, suggesting that gains in vocal sound levels made during LSVT LOUD treatment were maintained following the motor speech treatment block.

Intelligibility. lsvtf1 and lsvtm9 demonstrated significantly increased intelligibility ratings for untrained words and sentences, from follow-up LSVT LOUD/pre motor speech to post-motor speech. Although gains made in percent intelligibility for lsvtf7 were not statistically significant, she did display a visual trend of increased intelligibility for untrained sentences post- motor speech compared to measurements collected at follow-up LSVT LOUD/pre motor speech. Additionally, all four children displayed significantly higher ratings of percent intelligibility for untrained words and sentences, by unfamiliar listeners, following motor speech treatment compared to pre-treatment measures. This suggests that gains in percent intelligibility observed post-LSVT LOUD treatment were either maintained or further improved upon following motor speech treatment. These findings are consistent with those of Pennington and colleagues (2009; 2013), who reported that unfamiliar listeners understood significantly more single words and words in connected speech of children with dysarthria and CP, following a systems approach treatment that targeted body functions of respiration, phonation, and speech rate. These results also are consistent with those of Alton and Castro (2012) who reported improvements in overall intelligibility following a motor speech treatment.

One participant, lsvtf3, exhibited a visual trend that indicated a decreased percent intelligibility from follow-up LSVT LOUD/pre motor speech to post-motor speech, for both words and sentences. However, the reductions observed were not statistically significant. lsvtf3 did show a significant increase in percent intelligibility at post-motor speech compared to pre-treatment measures, indicating that although lsvtf3 did not make additional gains in intelligibility during the motor speech treatment block, she was able to maintain increases in intelligibility made during the LSVT LOUD portion of intervention. It is possible that the motor speech component of intervention was not intensive enough for this child to demonstrate continued improvements in intelligibility. A second dose of LSVT LOUD may have been more beneficial to achieve additional intelligibility gains for this child.

Listener Perception. Listeners preferred articulatory precision for one of four participants (lsvtf3) following motor speech treatment compared to pre-treatment measures, suggesting that increased control of the articulatory subsystem observed post-LSVT LOUD treatment was maintained during the motor speech treatment block. Given that intelligibility scores increased for all for participants following motor speech training, it may be that the perceptual task did not provide enough samples, listening opportunities, or both to detect subtle changes in articulatory precision following motor speech treatment. Intelligibility measures were derived from words and sentences totally 80 words thus, giving a better representation of sound sequences within word and sentence contexts. Perhaps SLP clinicians should rate preferences on a larger corpus of productions, which might increase perceptual preference for constructs such as articulatory perception.

Nasalance Scores. Three of the four children displayed nasalance scores that reached within normative values (i.e., within one standard deviation) of typically developing child speech on one out of the three reading passages (zoo passage, rainbow passage and nasal sentences). lsvtf1 and lsvtf7 both displayed increased nasalance scores at post-motor speech that fell within the range of values reported in pediatric norms (Baken & Orlikoff, 2000) for the nasal sentences and the rainbow passage, respectively. In contrast, lsvtm9's nasalance score for the zoo passage was reduced, but also fell within the range of normal following motor speech treatment. The Childers's Articulatory Synthesis Model has been applied to typically developing speech in previous research (Rong & Kuehn, 2012), to achieve phoneme-to-acoustic mapping and stimulate articulatory configuration in order to manipulate a reduction in hypernasality using articulatory adjustments (Rong & Kuehn, 2012). Rong & Kuehn (2012) report lowered mean nasality scores following articulatory adjustment, suggesting that reducing nasality can be achieved using this approach. These findings can begin to explain why nasalance scores, in the present study, were found to move in the direction of values reported in pediatric norms (Baken & Orlikoff, 2000), following a motor speech treatment aimed at driving the articulatory subsystem. The findings of lsvtm9, who displayed a reduction in nasalance, are consistent with the work of Wenke, Theodoros & Cornwell (2010) who reported reductions in perceived hypernasality and mean nasalance scores in individuals with dysarthria immediately following LSVT LOUD, suggesting that targeting vocal loudness by driving the respiratory/phonatory subsystem may positively impact the velopharyngeal subsystem in some people by elevating the overall *amplitude* of output across the speech mechanism. Although nasalance scores were not recorded at pre- and post-LSVT LOUD in the present study, it is possible that skills obtained through vocal loudness training during the LSVT LOUD block may have been maintained during the motor speech treatment, resulting in an observed reduction in nasalance scores for lsvtm9. Additionally, due to the nature of the nasalance calculation (nasal SPL divided by oral SPL plus nasal SPL) increases in vocal sound level could result in a reduction in nasal acoustic signals because of the corresponding increase in sound pressure, orally.

By comparison, lsvtf3 displayed nasalance scores that moved away from normative values. However, clinicians did not perceive samples as being closer to normal resonance for either follow-up LSVT LOUD/pre motor speech or post- motor speech measures for lsvtf3, indicating that there were no perceived changes in resonance for this participant across these time points. Therefore, although her mean percent nasalance slightly decreased following treatment, these changes may resemble more of a maintenance effect for lsvtf3, and not an increase in hypo-nasality.

Although spastic type dysarthria is typically associated with hypernasality (Duffy, 2013), the nasalance values in the present study suggest that three out of the four participants presented as hyponasal prior to receiving intervention. It is possible that there were other potential resonance issues being displayed by these children, such as cul-de sac resonance. Cul-de-sac resonance often occurs from altered tongue carriage resulting in sounds that get caught in another resonating cavity, such as the back of the pharynx behind the tongue (Rieger, 2015). As F1 and F2 values were found to more closely resemble those of typically developing speech following the motor speech component of intervention, it is possible that improvements in vowel space, specifically tongue height and advancement, may have contributed to nasalance values that approached normative values following treatment.

Further investigation of resonance is required for this population. For example, collecting VP opening measurements would be helpful to determine if an issue with timing was present for these children. This could be done by measuring the timing of VP closure for /p/ versus /m/ in the word hamper. It is common for children with CAS to have trouble sequencing speech sounds; therefore it is possible that there may have been an incoordination component to the resonance behaviors displayed by the children in the present study. Additionally, including a perceptual task, such as minimal pairs to contrast nasals with non-nasals may have been helpful to determine if percent nasality corresponded to nasalance patterns observed perceptually.

Speaking Rate (WPM). All participants exhibited a slower speaking rate at post-motor speech compared to pre-treatment measures. Additionally, lsvtf1, lsvtf7 and lsvtm9 displayed reductions in speaking rate from follow-up LSVT LOUD/pre motor speech to post-motor speech, indicating additional reductions in speaking rate following the motor speech treatment block. Previous literature has shown that children with dysarthria and CP have slower speaking rates compared to children with typically developing speech (Hodge & Gotzke, 2014; Chen et al., 2012). However, when looking at intelligibility as a byproduct of speaking rate, children with dysarthria and CP have lower intelligibility scores when speaking rate is faster and higher intelligibility scores when speaking rate is slower (Chen et al., 2012). Results from the present study conform to the work of Chen and colleagues (Chen et al., 2012), in that children who displayed an increase in percent intelligibility following treatment showed a corresponding decline in speaking rate. In contrast, lsvtf3's speaking rate remained fairly stable from pre- to post-motor speech treatment, suggesting that although further gains were not made during this treatment block, the previous gains made during LSVT LOUD treatment were maintained.

DDKs. lsvtf1, lsvtf7, and lsvtm9 displayed slower MRRmono rates on an AMR task following motor speech treatment compared to measures obtained at both pre-LSVT LOUD and follow-up LSVT LOUD/pre motor speech. The detected reduction in speaking rate over time corresponds to the observed reduction in syllables per second for these children (see Appendix A). Likewise, lsvtf3 and lsvtm9 demonstrated a similar trend for MRRtri rates on an SMR task, where the children produced fewer syllables per second following treatment. Consistent with work by Rvachew et al., (2005) and Terband et al., (2009), lsvtf1 and lsvtf3 were unable to produce a correct tri-syllabic sequence for an SMR task at the beginning of the study but were able to successfully complete this task following treatment, suggesting an increase in control of motor sequencing skills following motor speech treatment. Improvements in motor sequencing skills were expected following motor speech treatment as speech motor sequencing was directly targeted during this treatment. Acquisition of this skill may be related to increased practice with running conversational speaking, and practice of targets that were directly associated with sound sequences. In addition, motor learning principles (intensive practice with multiple repetitions) as described in the activity-dependent neuroplasticity literature (Schertz & Gorden, 2008; Kleim & Jones, 2008; Ludlow et al., 2008) may also have played a role in the acquisition of motor sequencing skills.

Proportion of Consonant Durations. lsvtf1 and lsvtf7 modeled a visual trend of shortened duration for consonant proportion following motor speech treatment compared to pre-treatment measures, whereas lsvtf3 and lsvtm9 modeled an opposing visual trend illustrated by a longer duration of consonant proportion. However, it is noteworthy to mention that for lsvtf1, lsvtf3 and lsvtf7 the time point corresponding to the shortest duration of consonant proportion was equivalent to the time point corresponding to the highest ratings of intelligibility, suggesting a relationship between consonant proportion and intelligibility ratings for children with dysarthria and CP. lsvtm9, who did not appear to follow a similar trend for intelligibility and consonant proportion, did exhibit a significant correlation between speaking rate and consonant proportion. The slower his speech became over time, the longer the consonant proportion, suggesting that this child utilized a different strategy to modulate intelligibility compared to strategies used by the other three participants.

Vowel Space. F1 and F2 values for each child, for at least one of three corner vowels, became closer to formant frequency values observed in typically developing child speech. Following motor speech, lsvtf3, lsvtf7, and lsvtm9 produced lowered F1 values for /i/ that moved closer to formant frequency values observed in speech by typically developing children (Peterson & Barney, 1952). Similarly, lsvtf1, lsvtf7, and lsvtm9 increased their F1 values for /a/ following post-motor speech treatment, resulting in formant frequencies that approach those reported in pediatric norms (Peterson & Barney, 1952). These results are consistent with Chen and colleagues (2012) who documented a limited F1 range in children with CP, accounted for by F1 values that are higher in high vowels such as /i/, and F1 values that are lower in low vowels such as /ɑ/. Because F1 corresponds with tongue height (Chen et al., 2012), F1 values that were found to more closely resemble those of pediatric normative values, suggests tongue height positioning, improved following motor speech treatment for the participants in the present study. F2 frequency values for /i/ heightened for lsvtf3 and lsvtf7, and F2 frequency values for /u/ lowered following treatment, for all four children, resulting in frequency values that moved in the direction of normative values. These results are consistent with reported findings by Sapir and colleagues (Sapir et al., 2007) indicating lowered F2 for /u/ and heightened F2 for /i/ following LSVT LOUD treatment, in adults with dysarthria. Unlike measures at post-LSVT LOUD that indicated lowered F2 values for /i/, F2 values for /i/ were heightened at post-motor speech, suggesting that additional gains were made following the motor speech treatment block that were not observed as a result of LSVT LOUD treatment alone. F2 value alterations following motor speech treatment suggest an increase in range of tongue movements, specifically in the front to back direction (Sapir et al., 2007).

Limitations

Four limitations of this study must be noted. A single-subject research design coupled with the small number of participants included in this study impedes the ability to generalize the outcomes to the larger population of children with mixed diagnoses of dysarthria and CAS secondary to CP. Secondly, although applying a lenient *p* value is consistent with *Phase I* treatment research, doing so increases the chance of making *Type 1* errors, therefore some of the treatment outcomes reported in this study may represent false positives. Furthermore, although variables of loudness, pitch, resonance, voice quality, and articulatory precision are accepted perceptions among speech-language pathologists, it is possible that the listeners may have interpreted the perceptual variables differently, as definitions for each variable were not given and sentence productions provided were limited. Finally, maintenance of effects was not examined following the motor speech treatment component of this study. In future research, longer-term maintenance of skills should be examined for both treatment types.

Summary

The present investigation explored the potential effects of combining LSVT LOUD treatment to target vocal loudness sequentially with a motor speech treatment to target articulation and speech motor sequencing. This *Phase I* study provides some evidence that the combination of two treatments targeting different components of the speech mechanism can facilitate speech gains in children with mixed diagnoses of dysarthria and CAS secondary to CP. The results from this study have the potential to advance our understanding of dysarthria and CAS as well as introduce a potentially efficacious treatment approach that target speech abilities within this population of children. This research will supplement current literature in the area of CAS, and may form the groundwork for future *Phase II* treatment studies.

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Appendix A

Table 10. *Speaking Rate in Syllables per Second.*

	Syllables per Second			
Participant	Pre LSVT	Post LSVT	Follow-Up LSVT/Pre Motor Speech	Post Motor Speech
lsvtf1	3.09	3.19	3.01	2.51
lsvtf3	3.11	2.66	2.87	2.82
lsvtf7	1.61	1.46	1.67	1.33
lsvtm9	3.17	1.98	2.04	1.72