Purpose: This study explores the importance of production frequency during speech therapy to determine whether more practice of speech targets leads to increased performance within a treatment session, as well as to motor learning, in the form of generalization to untrained words.

Method: Two children with childhood apraxia of speech were treated with an alternating treatment AB design, with production frequency differing in the 2 treatments. The higher production frequency treatment required 100+ productions in 15 min, while the moderate-frequency treatment required 30–40 productions in the same time period. One child was treated 3 times weekly for 11 weeks; the other child was treated twice weekly for 5 weeks. At the conclusion of each treatment phase, 5 min of probes were administered to determine whether generalization had occurred. Maintenance data to measure performance and learning were collected after a break from treatment.

Results: Both children showed improvement on all targets; however, the targets with the higher production frequency treatment were acquired faster, evidenced by better in-session performance and greater generalization to untrained probes.

Conclusions: Both treatment designs were effective, though frequent and intense practice of speech resulted in more rapid response to treatment in 2 children whose primary communication difficulty was childhood apraxia of speech.

Key Words: childhood apraxia of speech, motor learning, speech sound disorder, therapy, intensity

Childhood apraxia of speech (CAS) is a rare neurological, sensorimotor speech sound disorder (American Speech-Language-Hearing Association [ASHA], 2007; Caruso & Strand, 1999; Davis & Velleman, 2000; Maassen, 2002). The child with CAS demonstrates difficulty programming, combining, and sequencing the motor movements needed for volitional speech. These deficits often translate into poor intelligibility. CAS is a hard-to-treat speech disorder, with limited efficacy data on treatment approaches (ASHA, 2007).

To best treat CAS, it is important to understand its symptoms and to determine what characteristics differentiate CAS from other speech sound disorders (Ball, Bernthal, & Beukelman, 2002; Lewis, Hansen, Iyengar, & Taylor, 2004). While ASHA acknowledges a lack of consensus regarding diagnostic markers for the disorder, it has identified the three differential signs for CAS that currently have the largest evidence base (ASHA, 2007). Types of errors that differentiate CAS from other speech sound disorders include (a) inconsistent vowel and consonant errors in repeated productions of words and syllables (Betz & Stoel-Gammon, 2005; Davis, Jacks, & Marquardt, 2005; Smith, Marquardt, Cannito, & Davis, 1994); (b) difficulty with articulatory sequencing, often resulting in lengthened and disrupted transitions between words and syllables (Peter & Stoel-Gammon, 2005); and (c) inappropriate prosody (Odell & Shriberg, 2001).

While some debate exists in the literature as to whether CAS is solely a motor planning pathology or a disorder of linguistic as well as motoric origin (Ball et al., 2002), most agree that deficits in motor planning and programming are at the core of CAS (Crary, 1993; Maassen, 2002; Strand, 1995). It follows that treatments which are used to address CAS from a motor planning and sequencing framework target the disorder at its source. A variety of speech production approaches have been explored as possible treatments for CAS. Treatments with a speech production focus include integral stimulation (Rosenbek, Lemme, Ahern, Harris, & Wertz, 1973; Strand & Debertine, 2000), dynamic temporal and tactile cuing (DTTC; Strand, Stoeckel, & Baas, 2006), and Prompts for Restructuring Oral Muscular Phonetic Targets (PROMPT; Chumpelik, 1984). Currently, only integral stimulation therapy (Strand & Debertine, 2000) and its child-specific modification DTTC (Strand et al., 2006) have research evidence, in the form of single-subject design studies, to support their effectiveness.
At the core of many motor-based treatment approaches to speech lie at least some of the motor learning principles. These principles were designed to efficiently and effectively facilitate the learning of a new motor task (Schmidt & Wrisberg, 2004). Principles that affect motor learning include specific and repeated practice of the desired motor task (Rosenbek et al., 1973). Treatment guided by motor learning includes constant evaluation by the clinician of the use of blocked versus random practice, mass versus distributed practice, and knowledge of results versus knowledge of performance (Schmidt & Wrisberg, 2004). In addition, motor learning principles suggest the need for specific practice of the speech targets in various contexts that mimic real-life situations.

For treatment of speech motor deficits to be effective, intensive treatment is frequently recommended (e.g., Davis & Velleman, 2000; Hall, 2000; Maas et al., 2008; Strand, 1995). However, differences in treatment intensity have not been systematically studied with speech sound disorders and have received limited attention in other areas of motor learning. The current study explores treatment intensity effects by varying production frequency during intervention utilizing core principles of motor learning. A description of the core principles of motor learning is provided below, followed by an overview of the limited research on treatment intensity.

**Motor Learning**

When providing therapy to individuals with motor speech disorders, it is important not only that in-session improvement be observed but that the treatment conditions be designed to provide long-term improvement in speech. Motor learning therapy distinguishes between performance and learning. Motor performance is the accuracy of in-session behavior, while motor learning is the transfer of knowledge outside of the practice session (Schmidt & Bjork, 1992). The ultimate goal of learning is the generalization of skills to novel situations. This generalization is an indication of true learning and is achieved by incorporating the four main tenets of motor learning into therapy: (a) precursors to learning, (b) conditions of practice, (c) feedback, and (d) influence of rate.

**Precursors to Motor Learning**

Precursors to learning are concepts that are established with the client before treatment begins (Schmidt & Wrisberg, 2004). These precursors include establishing trust, informing clients of the goal of the treatment, and making certain that clients fully understand the tasks and procedures being implemented and why. Finally, clients must be focused and motivated to change (Strand et al., 2006).

**Conditions of Practice**

After establishing precursors to learning, optimal practice conditions are determined. These conditions include repetition, blocked versus random practice, mass versus distributed practice, and variability of practice (Ballard, 2001; Duffy, 2005; Schmidt & Wrisberg, 2004; Strand, 1995; Yorkston, Beukelman, Strand, & Bell, 1999).

**Blocked versus random practice.** Both blocked and random practice are important and are effective at different times in the learning process (Schmidt & Bjork, 1992). In blocked practice, one target is practiced at a time. Blocked practice is valuable when first learning a new skill, providing repetitive and numerous opportunities to practice movements necessary for skill acquisition. In random practice, more than one target is practiced in the same activity. In speech therapy, random practice is important when the child is ready to use a newly acquired speech production skill in a longer utterance or novel context. Blocked practice produces better in-session results (performance), and may be necessary for establishing new motor targets. Random practice may produce lower in-session results but leads to better generalization outside the session (Knock, Ballard, Robin, & Schmidt, 2000; Schmidt & Wrisberg, 2004; Schmidt, Young, Swinnen, & Shapiro, 1989; Swinnen, Schmidt, Nicholson, & Shapiro, 1990; Wulf & Schmidt, 1989, 1997).

Blocked and random practice may be used within the same treatment session and even the same activity, using a needs-based most-to-least hierarchical approach to supports (visual, verbal, tactile, etc.). These supports are faded as the child achieves higher production accuracy. Hierarchies can be used on a continuum of difficulty, with targets practiced at the syllable, word, phrase, or sentence level and in blocked or random forms of practice.

**Mass versus distributed practice.** Mass versus distributed practice can refer to the length of the session and the time between sessions. An example of mass practice is one 60-min session per week. Distributed practice could be three 20-min sessions over the course of the week; distributed practice has been shown to lead to greater learning (Strand & Debertine, 2000; Strand et al., 2006).

**Practice variability.** Variability of practice in and out of the clinic room has been shown to affect learning, promoting generalization to novel movement tasks and situations in which they may be used (Schmidt & Bjork, 1992; Wulf & Schmidt, 1997). Variability of practice may mean asking the client to practice speech targets in different word positions within words or in phrases, or in conversational speech or varying treatment settings. Variability promotes generalization and learning more effectively than consistent practice in which environmental and practice conditions do not vary (Wulf & Schmidt, 1997).

**Feedback**

Motor learning requires that children learn to monitor their own performance under different practice conditions through extrinsic and intrinsic feedback (Ballard, 2001; Duffy, 2005; Schmidt & Wrisberg, 2004; Schmidt et al., 1989; Swinnen et al., 1990; Wulf & Schmidt, 1989). Extrinsic feedback is information and a critique from the clinician regarding the client’s task performance. Extrinsic feedback includes knowledge of results and performance. Knowledge of results refers to the clinician telling the client whether the production of a speech target was correctly articulated. Knowledge of performance involves specific comments.
from the clinician regarding what clients did with their articulators, voice, or rate that led to the correct productions. Both types of extrinsic feedback are valuable during the learning process (Schmidt & Wrisberg, 2004; Schmidt et al., 1989). Knowledge of results feedback on every trial may lead to faster acquisition of the target, but feedback that is systematically faded over time leads to greater retention and generalization to novel situations of a learned motor sequence (Wulf & Schmidt, 1989). Feedback must take into account a client’s age and cognitive development; too-specific feedback with a small child may adversely affect performance and learning (Strand & Skinder, 1999).

Reduction of extrinsic feedback leads to greater intrinsic feedback (Schmidt & Bjork, 1992). Intrinsic feedback is a critique that comes from a client’s assessment of his or her performance, helping the client to develop self-monitoring abilities. This self-monitoring ability leads to self-awareness and the ability to analyze and correct one’s productions, resulting in true learning (Schmidt & Wrisberg, 2004).

Rate

Finally, rate of speech has an influence on learning. Reduced rate reduces difficulty in interactive overlapping motor tasks such as speech. Rate reduction decreases the mental load on the client and provides adequate processing time (Caruso & Strand, 1999; Strand, 1995; Wambaugh, Duffy, McNeil, Robin, & Rogers, 2006). The goal for the clinician is to slow down the presentation of the target utterance enough to lighten the client’s mental load. As the client becomes more successful at producing the utterance at the slower rate, the clinician can slowly increase the speech rate until it is similar to that of conversational speech (Caruso & Strand, 1999; Duffy, 2005).

Motor Learning Principles Applied to Speech Therapy

The majority of the evidence to support the effectiveness of motor learning principles in treatment comes from research in kinesiology. These principles have been explored extensively with limb motor learning and individuals with intact motor systems (e.g., Keetch, Schmidt, Lee, & Young, 2005; Perez, Lungholt, Nyborg, & Nielson, 2004). There are preliminary studies conducted with rats suggesting the functional reorganization of the brain after motor learning (Klein, Barbay, & Nudo, 1998).

In speech-language pathology, motor learning principles have been found effective in treatment research for individuals with acquired apraxia of speech (e.g., Freed, Marshall, & Frazier, 1997; Rosenbek, 1985; Rosenbek et al., 1973; Square, Chumpelik, Morningstar, & Adams, 1986; Wambaugh, Kalinyak-Fliszar, West, & Doyle, 1998). These principles are receiving more attention in treatment for other communication disorders as well. Studies exploring motor learning have increased with individuals who have swallowing disorders (e.g., Robbins et al., 2008; Sheppard, 2008), individuals who stutter (Namasivayam & van Lieshout, 2008), and aging populations (Schultz, Stein, & Micaleff, 2001).

A few recent studies have explored the effect of motor learning principles in pediatric speech disorders such as CAS and functional speech sound disorders (Skelton, 2004, 2007; Skelton & Funk, 2004; Strand & Debertine, 2000; Strand et al., 2006). Integral stimulation therapy is a motor-based, hierarchical speech treatment into which the principles of motor learning are incorporated. Hierarchies are used in a variety of ways, including beginning treatment with the easiest speech targets and moving to more challenging sounds or word shapes, making use of and fading a variety of cues, and varying the length of stimuli practiced in a hierarchical fashion. The original target population for integral stimulation was adults with acquired apraxia of speech; however, it has been modified to target the specific motor deficits seen in CAS (Strand & Debertine, 2000).

DTTC is based on integral stimulation therapy and motor learning principles. In integral stimulation and DTTC, targets can be practiced at the syllable, word, phrase, or sentence level. The client may be moved up and down the treatment hierarchy depending on the amount of support needed and the level of success achieved, which may vary from session to session. Multimodal cuing techniques are used in a hierarchical fashion as well and include auditory, visual, and tactile cues into the practice of speech production. These cues can be used together to provide maximal cuing to the client and can be reduced when less support is needed (Rosenbek et al., 1973).

To date, two studies have been published dedicated solely to determining the efficacy of integral stimulation therapy or DTTC for children with CAS (Strand & Debertine, 2000; Strand et al., 2006). Several unpublished studies also have demonstrated that integral stimulation is a beneficial treatment (Berman, Garcia, & Bauman-Waengler, 2007; Daniel, 2009; Jakieliski, Webb, & Gilbraith, 2006; Jensen & Gildersleeve-Neumann, 2005). These studies have shown that integral stimulation therapy is an effective treatment for remediating speech errors in children with CAS, while noting that more and larger studies are needed to confirm the benefits of the treatment for a wider group of children (Strand et al., 2006).

Strand and Debertine (2000) used a single-subject design with one 5-year-old girl with CAS. A limited set of functional phrases were trained according to the principles of integral stimulation therapy and motor learning. The child was seen in short blocks of time 4 days per week. Multiple opportunities to practice the movements for speech were used, as well as various modes of cuing. Improvement in intelligibility was observed for all targets treated. Strand et al. (2006) used principles of integral stimulation in combination with a multimodal cuing system in the slightly modified DTTC treatment, which focuses treatment mainly on the use of tactile cues. The single-subject design included four male children with CAS. The children were seen two times per day, 5 days per week, for 6 weeks. Again, a small number of functional phrases were trained, and the parents of the children were asked to practice speech targets at home each night. All children were nonverbal at the outset of the treatment. By the end of the 6 weeks, three out of the four children demonstrated marked improvement in speech intelligibility. Some generalization effects were seen as well.
Treatment Intensity

Intensity is frequently noted as critical for motor learning. In general, intense treatment is thought to increase the likelihood that the desired change in a behavior or situation will occur (Duhon, Mesmer, Atkins, Greguson, & Olinger, 2009). There are many ways a treatment can change a behavior, and the interpretation of intensity in treatment research can be conceptualized in a number of different ways (Maas et al., 2008; Warren, Fey, & Yoder, 2007). While intense treatment is frequently mentioned as a variable necessary for success, intensity is rarely quantified, nor is controlled evidence typically provided to show that the treatment intensity was a fundamental aspect of the treatment effect.

Differences in interpretations of treatment intensity have included the ratio of children to service provider (e.g., Graff, Green, & Libby, 1998), whether the intervention is provided one-to-one or in a small group setting (e.g., Duhon et al., 2009), number of hours of total treatment (e.g., Lovaas, 1987), whether treatment is behavioral or eclectic (Eikeseth, Smith, Jahr, & Eldevik, 2002), and number of hours per week of treatment (Robey, 1998). An understanding of all these aspects of treatment and of optimal levels of intensity is needed. Warren et al. (2007) outlined research to compare different levels of intensity in many areas, including treatment duration, frequency, number of teaching episodes per session, and form of treatment. For motor tasks, intensity in the form of mass practice conditions may be effective for initial performance but detrimental to learning, with shorter treatment sessions distributed over a longer time frame more likely to promote motor learning (e.g., Baddeley & Longman, 1978). With CAS, it is suggested that shorter, more frequent sessions will result in greater treatment effects than longer, less frequent sessions (Strand et al., 2006).

A motor learning variable in which the effect of treatment intensity is unknown is amount of practice. Schmidt and Lee (1999) propose amount of practice as a key variable in motor learning. They suggest that the more practice opportunities an individual has, the better the individual’s performance of a motor task will be, which in turn lead to greater learning of these motor tasks. In this case, a more intense practice session includes a higher number of repetitions and a faster overall pace. Motor reaching tasks conducted with animals have shown that large amounts of practice with reaching tasks resulted in cortical response difference; these changes in cortical response were not observed with smaller practice amounts (Kleim, Cooper, & VandenBerg, 2002; Luke, Allred, & Jones, 2004).

There are conditions in which large amounts of practice may be less beneficial. For instance, increasing practice of an activity in a repeated blocked manner may not promote learning, with less but more varied practice likely resulting in greater retention and generalization (Maas et al., 2008). It is also possible that too intense a treatment condition may decrease the client’s motivation to participate, resulting in both decreased performance and learning.

Researchers of acquired speech sound disorders have recommended large amounts of practice, but research specifically addressing practice amounts with adults has not been conducted (e.g., Chumpelik, 1984; Rosenbek et al., 1973; Wambaugh et al., 1998). Studies in the treatment of pediatric motor speech disorders also mention treatment intensity in the form of production frequency as a critical variable but do not provide quantification (e.g., Skelton, 2007; Strand & Debertine, 2000; Strand et al., 2006). In fact, the lack of research directly exploring the importance of practice amount is often cited as a limitation in the literature (Maas et al., 2008; Strand et al., 2006). To date, the effect of varying amount of practice by comparing production frequency has not been systematically studied in treatment for speech sound disorders.

To better understand amount of practice effects, the current study explored the variable of frequency of production in the context of integral stimulation therapy to determine whether more practice of speech targets leads to increased in-session performance as well as generalization to untrained words. Two treatment designs, both employing integral stimulation, were implemented. In the first design, referred to as the moderate-frequency (ModF) treatment, integral stimulation therapy, imitation, choral speaking, cuing techniques and principles of motor learning were used by the clinician, but relatively few productions (30 to 40) were elicited during a treatment session. In the second treatment design, referred to as the high-frequency (HiF) treatment, the same treatment protocol as in ModF was employed, but speech targets in HiF were elicited 100–150 times each during the 15-min treatment assigned. Data were tracked to determine whether changing the frequency of productions, while implementing integral stimulation, produced different results for remediating speech errors. It was hypothesized that children would achieve greater in-session production accuracy and generalization of speech targets treated with the higher frequency of production design.

Method

Design

In this study, two children with CAS were treated between two and three times per week for 40-min sessions. An alternating treatment AB design was used. Two treatment protocols were implemented across the two children. Each treatment was used in each session in a random order determined before the session began. Probes were administered in drill at the conclusion of each of the treatment phases. No feedback was provided during the administration of probes. Probes consisted of words containing the selected speech targets. Probes were used to determine whether generalization of trained speech targets had occurred in nontrained words.

Data were analyzed for pretreatment, baseline, treatment, and posttreatment sessions. Baseline sessions were conducted until stability or a decrease in accuracy was noted for each speech target. For both children, baseline was conducted over three or four sessions. One child was treated three times a week for 11 weeks, and the other child was treated two times a week for 5 weeks. Children were seen at the time of day that was convenient for their families, and that time was consistent across the study. After the conclusion of the study, a 2-week break was taken during which time the children did
not receive speech therapy of any kind. Maintenance data in the form of a standardized articulation test, a language sample, and probes were collected after the break from treatment.

Participants

The children in this study were two boys: Jamie, age 6;2 (years;months) at the beginning of the study, and Felix, 3;4 (both names are pseudonyms). Jamie and Felix had diagnoses of CAS, and both were recruited from a university clinic. The parent or guardian of each child completed a family and medical history questionnaire, and both were in good health prior to and during participation in the study.

Child 1: Jamie. Jamie had been adopted from China at the age of 2;2. He was born with a cleft lip and palate; at the time of the adoption, his lip had been repaired, but his palate had not. Jamie’s palate was repaired 1 month after arriving in the United States at the age of 2;3. His parents reported that he was a happy toddler who seemed to grow in every way except in speech and language development. He was reported not to have spoken his first word before being adopted, but he said “mama” shortly after arriving in the United States. Jamie’s speech skills did not improve as expected, and his parents noted that he did not say anything intelligible. The parents had him evaluated by a private speech-language pathologist when Jamie was 2; he was seen with limited success until he was 4;6. He also received early intervention services from his school district until he entered kindergarten.

Jamie began treatment at the university clinic at age 5. His expressive vocabulary was fewer than 10 words. His initial treatment focused on increasing communicative attempts. After 6 months of treatment at the clinic, Jamie produced enough speech to be diagnosed with CAS based on ASHA’s 2007 criteria.

At age 5, the lack of speech sounds in Jamie’s repertoire was remarkable. He produced few vowels and the consonant [m]. During treatment sessions, Jamie was noted to make inconsistent errors of consonants as well as vowels at the word and syllable levels. Errors typically included substituting glottal stops for target phonemes (when not allophonically appropriate), omitting target sounds, and substituting an [m] or vowel for the target phoneme. Word shapes were primarily CV, V, C, and CVCV. As early treatment progressed and he added new phonemes to his repertoire, Jamie demonstrated great difficulty sequencing individual sounds into syllables and words. For example, if he was asked to produce a multisyllabic word such as “banana,” he would mark each syllable with a vowel but would leave off the initial /b/ and often the first /n/ or mark each consonant with an [m]. If he did articulate the initial consonant as a /b/ or a /p/, he would often omit the first /n/ in banana. If he were asked to say two single-syllable words together such as “no way,” the pattern was similar. He would mark both words with vowels but leave off the initial consonant of each word. His prosody was affected, possibly due to his inability to sequence sounds, and the results were halting and arrhythmic speech. Six months prior to the current study, Jamie worked with the first author for 2 months using integral stimulation therapy techniques to increase his phoneme and word shape inventory.

At the beginning of the study, Jamie’s independent phonetic inventory, compiled from standardized testing and a language sample, consisted of [p, b, m, w, h]. In the pre-treatment speech sample, a number of phonological error patterns were noted, including glottal replacement/backing (18%), final consonant deletion (58%), and weak syllable deletion (24%). While Jamie produced a variety of word shapes, including CVC (14%) and CVCV (19%), he showed a preference for CV shapes (39%). Vowels were in error 53% of the time. Most monophthongs were produced during the sample. Diphthongs were often produced to mark a final consonant but were never produced accurately within a word. Jamie’s pretreatment percentage of consonants correct (PCC; Shriberg, Austin, Lewis, McSweeney, & Wilson, 1997) was calculated to be 25% in conversation.

An informal oral mechanism exam revealed a repaired lip and an intact but repaired palate. All facial features were symmetrical except for a slightly collapsed nares on the right side resultant from the lip repair surgery. Jamie demonstrated difficulty moving his tongue from side to side in a rapid motion and was noted to have difficulty sequencing any number of similar or different syllable strings in a row. Facial groping was noted with rapid movement of the articulators.

Although Jamie’s severely limited articulation made it difficult for most people outside of his family to understand him, he showed comprehension of language and its use. He used language to greet people, to ask questions, and to comment appropriately. He was an extremely social child with many friends in the community. He compensated for his unintelligible speech through the use of body language, facial expression, and a few signs to get his message across.

In Session 24, the use of an accuracy meter was implemented during the administration of probes to help Jamie maintain his motivation. The meter was a piece of paper with a red and green side and an arrow that moved between the two sides. Jamie was instructed that he was in charge of assessing whether he had made the correct sound by moving the arrow on the accuracy meter to the appropriate side of the paper—green for correct and red for incorrect—after he said the word. By using the accuracy meter in this manner, Jamie was not given a model of any kind before articulating the probe, but his motivation and desire to participate in probes were maintained, and intrinsic feedback regarding accuracy of productions was implemented.

During the course of this study, Jamie separately received language-focused treatment using an augmentative and alternative communication (AAC) device. He participated in the AAC treatment one time per week for a total of eight sessions over the course of the term. The language treatment included work on story grammar, syntax, turn taking, and topic maintenance skills using an AAC device. No articulation or speech treatment of any kind was administered during the course of the AAC treatments.

Child 2: Felix. Felix, who was recruited from the university clinic, had been receiving early intervention services since he was referred by his physician at 18 months of age. The most marked sign in Felix’s speech for a diagnosis of CAS was the disrupted transitions at the word and syllable
levels. He had great difficulty combining sounds to form words and was often heard to delete consonants or substitute other sounds for a target. His speech output was single words or expressive jargon, making it difficult to assess prosody. His errors were typically a sound substitution of the phone [d]. Vowel errors included the tendency to centralize back vowels and substitute the long vowels for short. Sequencing errors were noted that included repetition of the same consonant sound for each consonant in a word (i.e., consonant harmony) or omission of the consonant. His difficulty sequencing sounds, his severely reduced speech sound inventory, and his inconsistent consonant and vowel errors were sufficient to warrant inclusion in the study.

At the onset of the study, Felix had an independent phonetic inventory of [b, d, m, n, w, h]. His pretreatment PCC was calculated at 21%. His word shape repertoire was limited to CV (67%) and V (33%) word shapes. Significant error patterns at the phoneme level included fronting (66%), stopping (13%), and voicing errors (12%). Significant error patterns affecting word shape included final consonant deletion (100%), initial consonant deletion (10%), and cluster reduction and deletion (100%). While most monophthongs were heard at some point during the assessment, many monophthongs were diphthongized (19%), and overall vowel errors were at 58%.

An informal oral mechanism evaluation revealed intact and symmetrical oral structures. Felix was not asked to repeat syllable sequences or imitate facial movements due to his limited speech repertoire and his hesitance to participate in early testing activities.

To obtain baseline articulatory and receptive language scores, each child was administered the Goldman Fristoe Test of Articulation—Second Edition (GFTA–2; Goldman & Fristoe, 2000) and the receptive portions of either the Clinical Evaluation of Language Fundamentals Preschool—Second Edition (CELF–Preschool; Semel, Wiig, & Secord, 2004) or the Preschool Language Scale, Fourth Edition (PLS–4; Zimmerman, Steiner, & Ponds, 2002). A play-based speech sample was collected using toys or topics of interest to each child to assess intelligibility in running speech, to gather a phonetic inventory, and to perform an error analysis. A PCC measure was calculated for all consonant sounds produced during the speech sample (Shriberg et al., 1997). All testing took place at the university clinic. Treatment began for each child in the session after stable baseline measures were obtained.

**Treatment**

Treatment targets were chosen based on the analysis of their play-based speech samples, GFTA–2 scores, developmental appropriateness of the speech sound or word shape, and stimulability. Treatment targets for children with CAS were intended to improve motor planning skills in speech-like utterances. We considered both segmental and word shape targets. We decided to expand each child’s consonant inventory because of the children’s severely restricted consonant repertoire, resulting in an absence of place and manner categories for both, in relation to the diversity of word shapes. We selected targets to diversify the children’s existing sound inventories, practicing the target sounds in differing word and phrase positions to encourage the target sounds’ use in various word structures (Davis & Velleman, 2000).

Every effort was made to choose consonants that were different in place and manner to prevent generalization of one target sound to another target across the two types of treatments. Consonant targets were introduced primarily in functional CV, VC, CVCV, and CVC word shapes to increase both segmental and phonotactic skills (Velleman & Strand, 1994; Velleman & Vihman, 2002).

Due to Jamie’s tendency to default to glottal stops and the lack of alveolars in his speech sound repertoire, /t/ and /d/ were chosen and randomly assigned to the ModF treatment condition. The targets /f/ and /v/ were chosen to work on adding fricatives, a class he was not yet producing independently, to his speech sound repertoire and were assigned to the HiF condition.

Felix was assigned /θ/ and /ð/ because of the lack of independent production of fricatives in his pretreatment speech sound repertoire. These targets were randomly assigned to the ModF treatment condition. The targets /p, b, m/ were chosen because of their developmental appropriateness and assigned to the HiF condition. While single consonant targets were chosen for the purposes of tracking progress, the targets were always practiced at the syllable, word, and phrase levels depending on the accuracy of production at any given time. Targets were practiced in initial and final word positions when practiced at the word level. Sounds were never produced in isolation alone but were targeted in CV, VC, CVC, and CVCV word shapes.

Although the focus of treatment was production of targets in sequential movement accuracy, data tracking on accuracy for the purpose of pre/post comparison only took the target sound into account. For example, if the child was practicing the word “time” with the target being /t/, and the /t/ was produced accurately but the /m/ was omitted or in error, the production was still counted as correct. The clinician consulted with the children’s parents to identify words and phrases that were functional for the children in their school and home environments; these words then were targeted in sessions.

**Treatment approach.** For both treatment conditions, principles of motor learning were addressed through blocked and random practice, distributed practice, variability of practice, feedback, and attention to rate. Blocked practice was used when the child was acquiring a new speech target. The target was practiced at the syllable level until 80% accuracy was seen over two sessions; after this point, random practice was implemented. The target then was practiced in various words, phrases, or sentences in a randomized fashion. Once random practice was implemented, both types of practice were used in the session in a hierarchical fashion depending on the accuracy of target productions. Random practice of speech targets was used until an error occurred. Blocked practice of the single target was implemented after the error and until the sound was reestablished and the target was produced 5–10 times correctly.

Distributed practice was attempted through shorter sessions, more times a week when possible, and by asking the
families of the children to participate in home practice of target sounds. Home practice was functional and part of the families’ daily routines. Integral stimulation techniques were addressed in both treatment conditions through the use of the “watch me, and do what I do” technique and implementing cues in a hierarchical fashion. The cues used were implemented simultaneously as integral stimulation therapy suggests and were faded as needed. Cues used included auditory, visual, and tactile input. The clinician judged what level of cuing was needed. The clinician gradually lessened the support provided by fading cues.

The frequency of production variable was the only treatment condition that was manipulated during treatment sessions. During the ModF treatment, all integral stimulation techniques and motor learning principles were implemented, and 30 to 40 productions of each speech target were elicited. In the HiF treatment, the same treatment protocol was employed as in ModF, but speech targets in HiF were elicited 100–150 times each during the 15-min treatment assigned.

In both treatment conditions, the same types of activities and games were used to elicit speech targets, but more repetition was required for sounds treated with HiF. ModF differed from HiF in that there was more playing during the session and less elicitation of the speech targets. For example, if the participant was playing a board game to elicit speech in the ModF condition, he was asked to produce the speech target one to two times before taking his turn in the game. In the higher frequency treatment condition, he would be asked to repeat the target in a syllable, word, or phrase 10–15 times before taking a turn. ModF also differed from HiF in the level of intensity of the session. Intensity of practice was determined to be greater for the higher frequency of production treatment because (a) more practice of each target was occurring in the same time period (100+ vs. 30–40 productions,)(b) the pace of the session was faster due to more repetitions needing to be articulated in a short amount of time, and (c) more cues were being provided to the subject, again because of the number of targets being elicited. A nonoverlapping and closed set of speech sounds was targeted in a single type of treatment only.

Treatment sessions included the use of toys that were of interest to the child. An apraxia flip book (Faulk & Priddy, 2005) and small mirrors were used for visual cuing. The apraxia flip book contained five sections. Each section had all of the phonemes of English represented on cards that depicted a little girl making the sound. The target sound was also written below each picture. Target words could be phonemically “spelled” out using the flip book. The book provided a visual cue for the children when practicing desired targets. Tracking sheets were used by the clinician to tally the number of speech sounds elicited in each treatment phase. All sessions were videotaped or audiotaped. Videotaping was completed with a Sony DCR PC-101 digital camera and Sony Mini Digital Videocassettes. Audio taping was done using a Sony TCM-20DV standard cassette recorder.

Treatment order was randomized for every session. Sessions were generally two 15-min blocks with 5 min at the end of each treatment to administer the probes. The speech targets assigned to each treatment were practiced in various play activities, and data were tracked for all activities and sessions.

Baseline

Baseline probes were administered to each child for each of the speech sounds targeted. Baseline probes were implemented until stability or a decrease in accuracy was seen. Stability was defined as three sessions where accuracy of production remained the same. A decrease in accuracy was defined as any decrease in the accuracy of production of target sounds over three sessions. Baseline sessions consisted of the clinician and the client participating in language or reading tasks for 15–20 min with probes administered at the end of this period. This was done to establish a baseline session that would be similar in length to the treatment sessions to come. No practice of speech targets occurred during baseline sessions. Once the speech targets had been selected for each treatment, a list of 100–150 phonotactically similar words that had the speech target at the beginning or end of the word was compiled. Each word on the list was assigned a number. A list of 20 probe words and 10 foil words was compiled using a random number generator. No cuing or feedback was given during the administration of the baseline phase. Because of the children’s inability to read, targets were modeled for the children using a delayed model. Treatment began in the session after baselines were stabilized for each child.

Data Collection and Analysis

Data were collected during each activity for each treatment, and for all probes administered. During each activity, the clinician manually recorded the number of accurate productions of the targets and the number of attempts in a plus or minus column using an accuracy sheet. A manual counter was also used to track the number of productions of speech targets made by each child for each treatment phase. All sessions were video- or audiotaped for reference and assessment of fidelity of treatment. A percentage of correct in-session productions of targets was calculated using the tally of responses for each speech sound in each activity by dividing the number of correct productions by the number of attempts. This was utilized for both treatment conditions after the conclusion of every session.

Probes were administered at the end of each 15-min treatment condition to track generalization of trained sounds to untrained words. Posttreatment probes were chosen and implemented in the same manner as baseline probes. Probe responses were transcribed online during the session. Each transcribed production from the child was compared to the target transcription. A percentage of correct productions was calculated for each set of probes administered in each treatment condition by dividing the number of correct productions by the total number of attempts. These data were calculated and tracked for each session and plotted to show progress from session to session.

To compare efficiency of the ModF and HiF, we tracked the percentage accuracy for each treatment condition for within-session target productions (performance) and for
probe words (learning). We visually compared the two conditions for each child. We determined the magnitude of the effect of treatment condition using the standard mean difference for all data points (SMD\textsubscript{ALL}), determining the mean difference between ModF and HiF and dividing by the standard deviation. While there is yet no agreed upon method for determining effect size in alternating treatment single-subject design research, there is a growing consensus that similar effect sizes will be found with different effect size calculations. We selected SMD\textsubscript{ALL} because of its inclusion of all data points in the mean calculation and because it provides an interpretable effect size: Cohen’s \(d\) (Olive & Smith, 2005). The magnitude of the effect size was calculated as small (0.20–0.49), medium (0.50–0.79), and large (0.80 or greater; Cohen, 1988).

Each child was seen either two or three times per week for 40-min sessions, two 15-min treatments, and two 5-min probe sessions. Most sessions were held at the university clinic. Following treatment, a 2-week break was taken. After the break, maintenance measures were collected for each speech sound targeted during treatment and from each child.

A second observer, who was blind to the conditions of the study, phonetically transcribed random samples of probe words chosen from over the course of the study using broad IPA. This ensured interrater reliability and consistency of the transcriptions of target sounds made by the primary observer. Interrater reliability was completed for 5% of the data collected and was calculated as 91%. Transcribed targets that were not agreed upon during the second observer’s transcription were listened to by both transcribers again, and a consensus was established for all differences. The same second observer also viewed 5% of the videotaped sessions to ensure fidelity of treatments over the course of the study as well as to ensure comparability of all elements of Treatment A and Treatment B except for the frequency of production variable. Fidelity of treatment was calculated at 100%.

### Results

This study evaluated the effect of frequency of production on the acquisition and accuracy of speech targets during integral stimulation therapy and generalization of trained sounds to untrained words. Each child was treated with the ModF and HiF versions of integral stimulation therapy previously described. Specific speech targets in each treatment were selected based on the results from the standardized tests administered, as well as from the data collected from the language samples. Results of the two children’s pretreatment testing, baseline measures, treatment conditions, and posttreatment measures are discussed in the following section.

#### Jamie

**Pretreatment assessments.** Jamie attended three 40-min sessions each week for 10 weeks. Prior to baseline measures and treatment, pretreatment assessments were conducted. The GFTA–2 was administered, and Jamie received a standard score of <40, placing him below the 1st percentile for his age and gender. Receptive language testing was completed using the CELF–Preschool. Jamie received a standard score of 69 on the receptive language measures, placing him in the 2nd percentile. Jamie’s reluctance to participate in the receptive language test appeared to play a factor in the poor test performance. Due to his severe articulation errors and severely limited intelligibility, expressive language testing was not completed.

Pre- and posttreatment sessions were conducted. Each session lasted approximately 30 min. An analysis was conducted of Jamie’s phonetic inventory and errors during completion of the GFTA–2 and a 10-min spontaneous speech sample pre- and posttreatment. Phonetic inventory, significant error patterns, and PCC results are summarized in Table 1. As noted earlier, Jamie demonstrated a significantly reduced phonetic inventory, with only the consonant sounds [p, b, m, n, w, h] produced. During the pretreatment assessment, Jamie produced a total of 45 utterances during the 10-min sample. Intelligibility was calculated by transcribing all words in the language sample. Words that were not able to be understood either because of the large number of errors in the word or because of a lack of context were determined to be unintelligible. The total number of words in the sample was

<table>
<thead>
<tr>
<th>TABLE 1. Participants’ phonetic inventory, percentage consonants correct, and error patterns pre- and posttreatment.</th>
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<tbody>
<tr>
<td><strong>Participant</strong></td>
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<tr>
<td>Jamie</td>
</tr>
<tr>
<td>Consonant repertoire</td>
</tr>
<tr>
<td>Percentage consonants correct</td>
</tr>
<tr>
<td>Weak syllable deletion</td>
</tr>
<tr>
<td>Final consonant deletion</td>
</tr>
<tr>
<td>Consonant backing errors</td>
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<td>Vowel errors</td>
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<tr>
<td>Felix</td>
</tr>
<tr>
<td>Consonant repertoire</td>
</tr>
<tr>
<td>Percentage consonants correct</td>
</tr>
<tr>
<td>Fronting errors</td>
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<tr>
<td>Stopping</td>
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<tr>
<td>Final consonant deletion</td>
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<tr>
<td>Vowel errors</td>
</tr>
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</table>
then divided by the number of intelligible words to obtain a 58% intelligibility rate. Jamie’s PCC was calculated at 28% but necessarily included only the identifiable words in the language sample. A large number of consonant errors were noted, including errors that affected word shape, such as final consonant deletion (58% occurrence) and weak syllable deletion (24% occurrence). While Jamie produced a variety of word shapes, 39% of his words were CV shapes. Vowels were in error 52% of the time.

Jamie rarely attempted to self-correct, and facial groping was noted several times. His rate of speech was rapid. Jamie’s stress pattern was perceptually noted to be equal and excessive, with every syllable being produced with the same intensity in a staccato-like fashion. He imitated typical intonation but rarely produced typical intonation patterns spontaneously. Loudness, pitch, and vocal quality were within normal limits.

**Baseline and treatment results.** Baseline measures were collected over three sessions. As noted previously, the alveolar stops /t/ and /d/ were assigned randomly to the ModF treatment condition (30–40 productions), and the labiodental fricatives /f/ and /v/ were assigned to the HiF treatment condition (100+ productions). The targets chosen were not produced spontaneously during the initial testing.

After the initial testing had occurred, the clinician asked Jamie to imitate the facial movements needed to produce the sound (e.g., biting the lower lip and blowing air out for /f/) or the target sound itself. If he was successful in the imitation he was considered stimulable for the sound. During the baseline period, Jamie did not correctly articulate any of the target sounds in either treatment condition. During the treatment phase, the target phonemes were practiced in all word positions at the word and phrase levels in functional words and phrases that could later be used in his everyday speech. Data were tracked for accuracy of production of the target phoneme in all word positions.

Jamie was seen for a total of three baseline sessions and 32 treatment sessions. Twenty of the 32 treatment sessions took place at the clinic, eight took place at Jamie’s school, and four took place at his home. Every effort was made to minimize distractions in the different environments and to provide consistency of treatment across settings, but differences across settings were unavoidable. The different settings, however, resulted in variability of practice conditions for Jamie, important for motor learning.

Motor performance was assessed by tracking Jamie’s in-session performance for target speech sounds in each treatment condition. In-session performance was tracked across all sessions. Figure 1 shows the results for Jamie’s in-session (motor performance) progress for the target speech sounds in both treatment conditions beginning with the three baseline sessions, as well as all treatment sessions.

Blocked practice alone was conducted in Sessions 4 and 5. Blocked practice provided Jamie with frequent practice of the motor patterns for each target sound. Blocked practice also was implemented to give Jamie large amounts of successful practice at the syllable level before moving on to the word and phrase levels. Once it was determined that his accuracy of production at the syllable level was high, random practice was begun. Integration of both blocked and random practice in a hierarchical fashion was used for all other treatment sessions.

Jamie made steady in-session progress on the phonemes targeted in the HiF treatment. By Session 12, he was achieving 95% accuracy on words and phrases practiced in the session. A slight drop in accuracy can be seen in Session 13 with 82% in-session accuracy. Variability of productions was low across treatment sessions. Accuracy fluctuated between

![FIGURE 1. Jamie’s percentage of in-session productions correct for target speech sounds, measuring motor performance. Moderate-frequency (ModF) treatment, /t, d/, required 30–40 child productions per session. High-frequency (HiF) treatment, /f, v/, required 100–150 child productions per session.](image-url)
81% and 98% accuracy for the phonemes /f/ and /v/ targeted in the HiF with no change in slope noted for HiF.

Variability was higher for phonemes targeted in the ModF treatment, but an increase in slope can be seen over the course of the treatment. In-session accuracy fluctuated from 66% correct to 92% correct, but the higher levels of accuracy were not maintained from session to session. Sounds treated in the ModF treatment showed a decline in in-session accuracy of productions as the treatment phase of the study neared the end. Errors noted included leaving off the target sound or reverting to his typical substitution of /k/ or glottal stop instead of /t/ or /d/ in initial or final position.

Because of the high accuracy rate achieved for /f/ and /v/ in the HiF treatment, Jamie was able to practice these phonemes in more words and longer utterances during the course of the study. By the last session, he was producing four- to five-word utterances correctly with /f/ and /v/ target words. Sounds targeted with the ModF treatment were practiced at the phrase level, but in two- to three-word utterances only. In longer utterances, accuracy of the ModF target sounds would decrease, so practice would be scaled back to achieve correct production and higher accuracy.

Motor learning was assessed through the administration of probe words at the end of each treatment condition within the session. Probe words contained trained sounds in untrained CV and CVC words. Figure 2 shows accuracy of probe productions for both treatment conditions for the three baseline sessions, all treatment sessions, and the posttreatment probes that were administered. While accuracy rose as high as 60% for /f/ and /v/ probes (HiF), stability across more than two sessions was never attained. Jamie’s accuracy in probe words, however, rose from 0% across three baseline sessions to as high as 60%. Probes for the ModF treatment, while showing improvement over baseline testing, never came close to the accuracy that was achieved for the /f/ and /v/ probe words. Jamie never accurately articulated /d/ in any of the words targeted in the practice session or during the administration of probes after the practice session. He produced a [t] for any word containing a /d/. Data were tracked and graphed based on accuracy of productions without taking voicing into account after the practice session and during the administration of probes. Either phoneme /t, d/ or /f, v/ were accepted as correct. These data showed that even without taking voicing into account during the administration of probes, accuracy levels for the sounds treated with ModF never rose above 65%, while accuracy for sounds treated with HiF attained 85% accuracy in Session 30.

The effect size for the difference between treatment conditions was calculated using Cohen’s $d$. The difference in Jamie’s accuracy between HiF and ModF conditions was large for within-session productions ($d = 1.59$) and moderate ($d = 0.71$) for nontargeted probe generalizations.

**Posttreatment results.** Posttesting was conducted after a 2-week break from all speech therapy. Posttesting was completed using data from the GFTA–2, probes, and a speech sample. Probes were conducted as during the course of the study. Jamie received a standard score of <40 on the GFTA–2 that placed him below the 1st percentile. Analysis of the results from the GFTA–2 showed that while Jamie acquired some new speech sounds, he did not articulate these sounds during the posttreatment assessment. Posttreatment probe measures were taken for each treatment condition. Probes were administered in the same fashion as those during the treatment phase. Accuracy of production for the ModF treatment was 15%, showing a decline of 5% over the 2-week break. Posttreatment accuracy of the HiF treatment probes was 45%, showing an increase in accuracy from 35% in the last treatment session. This maintenance of accuracy rates suggests that motor learning had occurred for the /f/ and /v/ phonemes that were treated with the HiF condition.
Jamie demonstrated a significantly reduced speech sound inventory in the pretreatment measures. His posttreatment speech sample included all of the sounds produced in the pretreatment sample as well as [t, f, v, n], and [l]. During the posttreatment speech sample, Jamie produced a total of 30 three- to five-word utterances. His PCC was calculated at 73%, which was an improvement over his PCC of 28% during pretreatment measures. Intelligibility for the posttreatment speech sample was calculated at 70%. All sounds treated over the course of the study were articulated correctly in the speech sample. Final consonant deletion errors were reduced from 58% in the pretreatment measure to 13% in the posttreatment measure. Backing errors were reduced from 25% to 0%. Weak syllable deletion was reduced from 24% in the pretreatment measure to 10% in the posttreatment measure. Cluster reduction and deletion errors remained the same at 100% error. Vowel errors decreased from 52% to 37% between pre- and posttreatment assessments. Derhoticization errors occurred in the posttreatment sample (there were no rhotic vowel targets in the pretreatment sample). Jamie’s utterance length increased from one- or two-word intelligible utterances during the pretreatment speech sample to four- to five-word intelligible utterances during the posttreatment sample.

In general, the suprasegmental features of Jamie’s speech remained the same. He still tended toward an overly rapid rate, and his equal and excess stress became more apparent, possibly due to the fact that he was producing longer utterances in the posttreatment speech sample. Loudness, pitch, and intonation were not treated over the course of the study and did not differ in the final speech sample.

**Felix**

**Pretreatment results.** Felix attended two 50-min sessions per week. All sessions were conducted at the university clinic. The auditory comprehension portion of the PLS–4 was administered 1 month before Felix was recruited into this study. Felix received a standard score of 96 on these measures, placing him in the 39th percentile for his age. Due to his severe articulation issues, the expressive portion of the test was not administered. The GFTA–2 was attempted but was not completed.

A speech sample was used to analyze Felix’s speech sound repertoire and errors, and to choose targets for treatment. During the speech sample, Felix produced a total of 63 one- and two-word utterances. His PCC was calculated at 21%; intelligibility was approximately 50%. Felix presented with a significantly reduced speech sound inventory for his age and a sound preference for the phone [d] that served as a default for most consonants. Table 1 provides a summary of Felix’s consonant inventory, error patterns, and PCC pre- and posttreatment. His word shape repertoire was limited to CV and V word shapes. A total of 39 errors affecting word shape were made; final consonant deletion (100%), initial consonant deletion (10%), and cluster reduction and deletion (100%) occurred frequently. Vowels were in error 58% of the time. While most monophthongs were produced at some point during the assessment, many monophthongs were diphthongized (19%). Prosody was not assessed due to a lack of connected speech. Informal assessment of Felix’s voice and speech rate judged them to be within normal limits.

**Baseline and treatment results.** Baseline measures for Felix were conducted over three sessions. The phonemes /f/ and /v/ were randomly assigned to the ModF treatment, and the phonemes /p, b, m/ were assigned to the HiF treatment. As with Jamie, all target phonemes for Felix were treated in syllables and in initial and final word positions in functional words and phrases. Baseline measures remained stable at 5% accuracy for /f/ and /v/ over the three baseline sessions, while /p/, /b/, and /m/ showed a decline from 40% to 20% during the baseline testing.

Figure 3 displays motor performance of Felix’s in-session progress for both treatment conditions. The HiF treatment
shows greater accuracy and stability, with variations in accuracy between 90% and 97%. Little variability is seen between sessions for sounds treated with HiF, and there is no change in slope. The phonemes /f/ and /v/, treated with the ModF treatment, show a lower level of accuracy overall and greater levels of variability from session to session. Due to high fluctuation in the accuracy of words treated with ModF, these sounds were treated only at the syllable level and in CV or VC words. Accuracy of phonemes treated with ModF ranges from 3% to 71%.

Figure 4 illustrates motor learning and shows generalization of trained sounds to untrained words. Figure 4 depicts performance on the three baseline sessions, the probes administered after each treatment phase, and the posttreatment probe measures. Probes for /f/ and /v/ in the ModF treatment show increased progress over the course of the study, with accuracy ranging from 0% during all three baseline sessions to 20% in Session 11. Probes for /p/, /b/, and /m/ in HiF treatment show a range of accuracy from 20% in the last baseline measure to 55% in Session 10. None of the probes show stability over time; in fact, accuracy of probes administered for HiF decline sharply after Session 11. These results suggest that motor learning has not yet occurred for the target speech sounds.

Treatment condition effect size was calculated using Cohen’s $d$. The difference in Felix’s accuracy between HiF and ModF conditions was large for both within-session productions ($d = 1.62$) and nontargeted probe generalizations ($d = 1.73$).

Posttreatment results. Posttreatment measures were conducted 2 weeks after the intervention sessions had ended. Felix received a standard score of 53 on the GFTA–2, placing him below the 1st percentile. Two sets of probes were administered, one for each treatment condition, to assess retention and generalization of treated speech sounds. Accuracy on probes administered in the ModF treatment was at 0%, showing a drop in accuracy from 15% during the last treatment session. Probes administered for the HiF treatment showed 50% accuracy, an increase in accuracy from 30% during the last treatment session.

During collection of a spontaneous play-based language sample, Felix produced a total of 53 one-, two-, and three-word utterances. The posttreatment sample shows an increase in the number of two-word utterances: in the pretreatment measure, out of 63 utterances, only 11 were two words, while in the posttreatment measure, 16 of 53 utterances were one word, and two were three words. His PCC was 32%, an increase over his pretreatment score of 21%. Intelligibility was calculated at 74% in the same manner as before, an increase over the 50% intelligibility calculated for the pretreatment measure. Errors affecting word shape also decreased. Fronting errors were reduced from 66% to 23% in the posttreatment assessment. Final consonant deletion fell from 100% to 71%, and stopping errors were reduced from 13% to 4%. Vowel errors were reduced from 58% in pretreatment to 33% in the posttreatment measure. Word shape was still severely limited in the posttreatment measure, and Felix’s preference for CV and V word shapes persisted, but there was an increase in the number of CV words produced. Felix produced CV words 67% of the time in the pretreatment sample and 87% of the time in the posttreatment sample. He added the CVC word shape to his repertoire in 2% of the sample words. Even though Felix began to use longer utterances, it remained difficult to determine whether the suprasegmental aspects of his speech were typical. Loudness, vocal quality, and rate appeared to be within normal limits. Felix did not produce enough longer utterances to accurately assess stress and intonation.

**Discussion**

The hypothesis that higher numbers of productions of speech targets, or greater frequencies of production, lead to increased motor performance was tested in this study. This frequency effect would be indicated by increased accuracy of those speech sounds in practice words leading to motor

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**FIGURE 4.** Felix’s percentage of correct postsession probe productions for target sounds, measuring motor learning. ModF treatment = /f, v/; HiF treatment = /p, b, m/.
learning, as found by generalization of trained sounds to untrained words. The importance of production frequency is discussed below, in relation to each child participant as well as compared in the HiF and ModF conditions.

**Overall Effectiveness of a Motor-Based Treatment Approach**

Both children appeared to benefit from the integral stimulation treatment utilizing motor learning principles during the course of the study. Both children made progress on all speech targets treated in each treatment condition. All consonants treated showed an increase in accuracy of production from baseline and over the course of the study. Jamie expanded his speech sound repertoire, and his consonant accuracy rose from 25% to 73% in 11 weeks. Final consonant deletion was reduced from 58% in the pretreatment measures to 13% in the posttreatment measures. Although final consonant deletion was not specifically targeted, it is not surprising to see that errors of this kind were reduced in number. Because all target phonemes were treated in syllables as well as in initial and final word positions in functional words and phrases, Jamie was given the opportunity to practice marking final consonants. Felix added a new word shape to his repertoire and increased his level of intelligibility from 21% to 32% in 5 weeks.

**Comparison of Treatment Conditions**

While both children appeared to benefit from other aspects of their treatment, the data indicate that learning and maintenance of skills for both children was greater for speech targets treated with more intensity—that is, a higher frequency of production. The effect size for treatment condition was large for motor performance tasks in both children and for motor learning for Felix; motor learning effect size for Jamie was moderate. Data show that the speech targets treated with the HiF condition led to higher in-session accuracy and greater generalization effects for both children than for speech targets treated with the lesser number of repetitions in the ModF condition.

The treatment differences observed may be due to the greater intensity and pace of the HiF condition in which the subjects had more opportunity for practice of speech sounds and received more cues when needed. Not only did speech targets treated with a higher number of productions and a greater level of intensity show higher levels of accuracy overall during the course of the treatment, but high levels of accuracy were achieved in fewer sessions than targets treated with fewer productions. Speech targets treated with a high number of productions showed less variability, meaning accuracy did not vary from session to session as much as it did for targets treated with fewer productions. Speech targets treated with more productions generalized better to untrained words and showed more stability overall. Both children also demonstrated better retention of the targets treated with more productions during the posttreatment probes.

Motor learning was observed in the change from the three baseline probe sessions, in which Jamie’s accuracy was 0%, to the treatment phase, in which Jamie’s accuracy for the HiF treatment probes was 35%. This accuracy elevated to 45% in the posttreatment session. Accuracy of production of speech targets treated with the ModF treatment rose from 0% at baseline to as high as 92% in Session 29. The speech targets treated with a higher frequency of production and greater intensity (more productions, faster pace, and more cues) saw greater overall progress and generalization; in addition, speech targets treated with the moderate frequency of production progressed as well. While Jamie never reached 80% accuracy on any probe measure during the treatment phase, posttreatment probe accuracy increased, and skills were maintained after the 2-week break.

Felix also made progress over the course of the study. In-session accuracy of targeted sounds rose for both treatment conditions, suggesting an increase in motor performance. Again, speech targets treated with the higher frequency of production condition showed greater progress, but progress was seen in both treatment conditions. Accuracy of in-session productions for the ModF treatment rose from 0% at baseline to 68% in the last session. Accuracy for HiF targets was consistently high throughout the study. Felix’s consonant accuracy rose from 21% to 32% in 5 weeks of treatment. He showed maintenance of skills for consonants treated with the higher frequency of production during posttreatment probes. Posttreatment probe scores rose, suggesting that some motor learning had occurred.

**Effects of Intervention Focused on Motor Learning**

This study included only two children, both diagnosed with CAS. While both children increased in their accuracy of speech during the course of this intervention, there were differences in their responses to treatment. Below, we briefly explore some of these individual responses to treatment as examples of varying individual needs during the motor learning process.

Jamie clearly improved his speech during this intervention research period. The motor learning principles and cuing system components of integral stimulation therapy seem to have helped Jamie achieve gains in the acquisition of speech skills in general as well as adding a new class of speech sounds, fricatives, to his repertoire. More specifically, he made the most gains in the consonants /f/ and /v/ treated with the higher frequency condition.

Although generalization to untrained probe words never reached levels of 80% or better and showed variability across sessions, generalization was seen for both treatment conditions. While both conditions saw some generalization effects, the greatest generalization was seen for the HiF condition. It is likely that the frequency of production, intensity, and consistency of the sessions over the course of the study led to greater practice time overall, which in turn led to greater success for Jamie. As he experienced more success, his confidence grew, and his motivation to practice intensely increased. He began to self-cue using the tactile cues developed in treatment and to self-correct in sessions, as well as in his other environments.

While Jamie experienced success over the course of the study overall, there were fluctuations in the accuracy of probe word productions. It appeared that the variability was
an issue of motivation in the production of probe words. When Jamie’s probes appeared to not truly be measuring ability, the probe administration was altered with the implementation of the “accuracy meter,” used after production for Jamie to self-critique and the clinician to provide feedback. Accuracy of probes for the HiF treatment increased from 5% in Session 24 to 30% in Session 25 when the meter was introduced. Accuracy remained between 30% and 45%, with one session reaching 60% using the meter. Probes for the ModF treatment also increased in accuracy, less than for HiF probes, ranging from 10% to 45%. As the accuracy meter lost its novelty near the end of the study, accuracy once again declined. These results echo those of Strand et al. (2006), who found motivation to be a key factor in determining progress over the course of treatment.

Felix had only 5 weeks of treatment. Felix’s lack of motor learning, evidenced by low accuracy of probe productions, could be due to the limited treatment period. While the precursors to motor learning were not established with Felix at the outset of the study, he and the clinician began to bond and develop trust as treatment progressed. His young age may also have contributed to the lack of motor learning. Alternatively, it is possible that some improvement in speech targets resulted from overall maturity and not just the treatment. Nevertheless, it is our belief that in the future, if many precursors to motor learning were met and a longer treatment regimen with a focus on high-frequency production were implemented, Felix’s progress could be even more significant than it was during his participation in this study.

Limitations and Cautions

While the broad outcomes of the study indicate that higher frequencies of production and larger amounts of practice of speech targets can benefit children with CAS, there are limitations to the findings. The small number of participants in the study makes generalization of the data to other children with motor planning deficits difficult. Larger scale studies are needed to replicate these results with more children diagnosed with CAS.

Variability in the implementation of the treatment protocol is also a limitation of the study. Jamie received 11 weeks of treatment, while Felix received only 5 weeks of treatment. Other factors that differed between the subjects were the variability of the practice situations and the amount of distributed practice achieved for each subject. The variability seen in the probe data for Jamie should be interpreted with caution due to the possibility of motivational issues. The data from Felix should also be interpreted with caution because of the limited number of sessions he received and the issues relating to age and the precursors to motor learning that were discussed earlier.

Finally, while all speech targets were tracked at the segmental level, all targets were always practiced at the syllable or word level in a variety of word positions at the word, phrase, and sentence levels. While consonant accuracy was measured to track progress, the focus during intervention was to practice the consonants in syllable and word sequences, as is considered best practice for children with a motor planning disorder. This kind of practice appears to have improved the phonotactic repertoires of both participants. It is unclear, however, what type of phonotactic progress may have been made if we had focused measurement on phonotactic rather than segmental goals.

Conclusions

The results of this study indicate that high-frequency practice of speech targets in the context of therapy utilizing motor learning principles resulted in seemingly quicker acquisition of the targets, better in-session performance, and more generalization to untrained probe words than lower frequency practice for two children with CAS. The results also outline important considerations for clinicians in treatment design.

Research implications of this study mirror those proposed by others (Strand & Debertine, 2000; Strand et al., 2006). Motor learning principles applied with a multimodality stimulation treatment such as integral stimulation can be an effective tool for remediating speech sound errors in children with CAS. This study also shows that the ability of the clinician to motivate the client and the foundation of therapy in the form of the principles of motor learning are important to the success of this treatment (Strand et al., 2006).

Finally, as has been indicated by researchers in this area (Ball et al., 2002; Davis & Velleman, 2000; Forrest, 2003; Lewis et al., 2004; Shriberg, 1994), children with CAS can be a difficult population to work with based on their slow progress in therapy and the severity of their articulation issues. Like any population of children with severe speech and language disorders, children with CAS benefit from the most efficacious and time-effective treatment available. Continued research with children with CAS is needed to address the importance of other motor learning principles in efficacious treatment.

References


