APRAXIA OF SPEECH: CHANGE IN ERROR CONSISTENCY FOLLOWING A MULTIMODAL INTENSIVE TREATMENT (MMiT)

By

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To Grandma Szeles, who taught me that communication is both a gift and an art,
to be cherished deeply and practiced frequently

May she rest in peace

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LIST OF ABBREVIATIONS

ABA-2	Apraxia Battery for Adults, second edition
Aphasia	Language impairment
Apraxia of speech	A motor speech disorder, caused by disrupted motor planning and programming for speech movements
AQ	Aphasia Quotient; a measure of overall severity of language impairment obtained in the Western Aphasia Battery
CTOPP	Comprehensive Test of Phonological Processing
Dysarthria	A motor speech disorder, caused by neuromuscular deficiency
LAC-3	Lindamood Auditory Conceptualization Test, third edition
MMiT	Multimodal Intensive Treatment
MSE	Motor Speech Examination
Oral apraxia	A motor speech disorder, characterized by impaired production of non-speech oral movements
Phonological alexia	A post-stroke reading disorder, characterized by impaired ability to “sound out” words based on individual phonemes
SLP	Speech-language pathologist
WAB	Western Aphasia Battery

Abstract of Thesis Presented to the Graduate School
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By

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Post-stroke apraxia of speech is a motor speech disorder thought to result from disrupted motor planning and/or programming (Darley, 1969; Ogar, Willock, Baldo, & Wilkings, 2006; McNeil, Doyle, & Wambaugh, 2000) and often seen in combination with other language or motor speech disturbances. Among originally implicated features of the disorder is error inconsistency, or variability in performance across repeated attempts at the same utterance (Johns & Darley, 1970; LaPointe & Johns, 1975; Deal & Darley, 1972; Mloch, Darley, & Noll, 1982; Wertz, LaPointe, & Rosenbek, 1984), which has been recently challenged by several investigators (Odell, McNeil, Rosenbek, & Hunter, 1990; Mauszycki, Dromey, & Wambaugh, 2007; Wambaugh, Nessler, Bennett, & Mauszycki, 2004, McNeil, Odell, Miller, & Hunter, 1995).

During previous intervention efforts with patients enrolled in a Multimodal intensive Treatment (MMiT) for phonological alexia, a post-stroke reading disorder, subjective changes in verbal praxis were reported (Conway, Heilman, Gonzalex-Rothi, Alexander, Adair, Crosson, & Heilman, 1998; Kendall, Conway, et al., 2003; Kendall, Rodriguez, et al., 2006; Kendall, Rosenbek, et al., 2008). This treatment intensively trains the unique

multimodal features of phonemes and works to implement learned phonological principles through extensive sensorimotor practice. Thus, it was proposed that MMiT might provide a mechanism for improved oral motor programming in individuals with apraxia of speech and likewise, skills for more consistent and accurate production.

As patterns of error consistency in apraxia of speech remain largely unresolved, the influence of theoretically based interventions on resulting patterns of error has not yet been explored. Therefore, the purpose of this Phase I research project was to examine change in error consistency in both number and location across successive repetitions of the same target words, before and after MMiT.

In the context of a single-subject repeated measures design, three participants with apraxia of speech and aphasia underwent 120 hours of MMiT. We administered the Repeated Trials subtest of the Apraxia Battery for Adults, second edition (ABA-2, Dabul, 2000) at pre- and post-treatment as the dependent variable. Consistency in total number and location of errors across successive repetitions of the same utterance was calculated at each time point.

Following MMiT, the total number of errors produced across all 30 responses (three responses for each of 10 target items) decreased for two participants. One participant did not show this reduction, demonstrating a total of 5 errors at both pre- and post-treatment. Small and medium effect sizes were seen following MMiT for reduced error inconsistency (change in total errors across successive repetitions) in all three participants, and all three demonstrated increased consistency of error location. Rates of consistency in error location across sessions were minimal for all three participants.

Preliminary findings support previous reports of improved verbal praxis in adults with post-stroke apraxia of speech. By incorporating extensive motor practice of learned phonological principles during training, MMiT may strengthen skills for formulating, accessing and implementing associated oral motor programs. In turn, these treatment approaches may also strengthen the consistency and/or accuracy of performance. Additional participant and follow-up data is needed to determine the viability of MMiT for recovery in apraxia of speech and identify patient-specific characteristics which might influence treatment outcomes.

CHAPTER 1
INTRODUCTION

Apraxia of Speech Definition, Significance, and Diagnosis

Apraxia of speech, or verbal apraxia, is a motor speech disorder characterized by nonfluent articulation and marked difficulty in the production of speech sounds. Deficits associated with the disorder may severely restrict the consistency, quality, and intelligibility of speech and may limit both educational and employment opportunities, as well as communication with friends and loved ones.

While apraxia of speech may result from brain trauma, tumors, or neurodegenerative disease (Ogar, Slama, Dronkers, Amici, & Gorno-Tempini, 2005), it is most often seen following damage to the left hemisphere as caused by vascular occlusion, or stroke (Duffy, 1995). Strokes in this population occur most often within the middle cerebral artery, which subserves the majority of sites in the brain associated with language comprehension, organization, and production.

It has been theorized that apraxia of speech is due to a disruption in the motor planning and programming required for speech (Darley, 1969; Ogar et al., 2006; McNeil et al., 2000), at a level between language (or the underlying message) and execution (or production of the message through overt communication). This is distinct from aphasia, which reflects a disruption in "the ability to manipulate aspects of language, including sentence structure and word usage…and the internal evocation of phonemic and graphemic representations" (Square, Roy, and Martin, 1997, p. 173) and dysarthria, a motor speech disorder which may result from "muscle weakness, aberrations of tone or peripheral biomechanical incoordination" (Square et al., 1997, p. 174). Rather, apraxia of speech represents a disruption in the ability to select and implement the proper oral motor programs for movements within the lips, jaw, tongue,etc. In turn, patients with apraxia of speech in the absence of other speech or language deficits may struggle to position their mouth appropriately during volitional speech, despite knowledge of the message they wish to convey and capacity for the required strength and range of articulatory movements.

Since the initial characterization of apraxia of speech by Darley in 1969, controversy over differential diagnosis continues due to a range of features that exist in other language and motor speech disturbances. Such features include noticeable groping or attempts to control the oral articulators during speech, slowed or effortful speech, attempts to self-correct speech sound errors during production, greater difficulty articulating words of increased length or complexity, and relatively intact automatic, but diminished volitional speech (Knollman-Porter, 2008; Wambaugh, Duffy, McNeil, Robin, & Rogers, 2006). Though many of these symptoms have been traditionally attributed to apraxia of speech, they may also be the result of muscle weakness or diminished muscular control (dysarthria), impaired language comprehension, poor language processing or deficient phonological planning (aspects of aphasia), or deficits in motor control for non-speech oral movements (oral apraxia) (West, Bowen, Hesketh, & Vail, 2008).

Thus, while apraxia of speech is not due to underlying language or neuromuscular deficits, widespread brain damage due to vascular occlusion results in high rates of comorbidity with other language and motor speech disorders. In turn, cases of “pure” apraxia of speech are extremely rare and findings for these individuals may not generalize to most clinical samples (Duffy, 2005). These complications make the objective assessment of apraxia of speech within this context a challenging, but clinically necessary endeavor.

Error Inconsistency in Apraxia of Speech

Among originally implicated features of apraxia of speech is the pattern of error inconsistency, or variability in performance across repeated productions of the same utterance (Johns & Darley, 1970; LaPointe & Johns, 1975; Deal & Darley, 1972; Mloch et al., 1982; Wertz et al., 1984). Although originally considered a core trait of the disorder, recent investigations have called this feature into question, suggesting that errors may instead be highly predictable for specific phonemes across various target words (Wambaugh et al., 2004; Mauszycki et al., 2007; Odell et al., 1990), across repeated productions of the same target word (McNeil et al., 1995) and across sampling occasions (Mauszycki, Wambaugh, & Cameron, 2010). Despite earnest efforts to understand and predict error patterns, recent investigations have raised as many questions about the nature and clinical manifestation of speech sound errors in apraxia of speech as they have clarified.

Attempts to demonstrate the consistency of performance across time for example, have produced little agreement in the literature. Mauszycki and Wambaugh (2006) for example, reported changes in the total number and position of errors (initial, medial, or final) across sampling sessions. Similarly, greater predictability of errors across sampling sessions has been shown for certain phonemes, with greater change occurring for other phonemes across repeated sessions (Mauszycki et al., 2007). As these studies were limited to observations conducted with a single participant, Mauszycki et al. (2010) conducted a group analysis of 11 individuals with apraxia of speech and aphasia in an attempt to replicate findings. This study instead revealed a high degree of consistency in the total number of errors and patterns of performance for specific phonemes across repeated sampling. Thus, it remains unclear whether the location of errors (presence of errors for certain phonemes) generally varies over repeated occasions for individuals with apraxia of speech, or if changes in each individual’s performance are obscured by group analysis.

Additional debate remains in the literature regarding whether error consistency (for specific phonemes across different exemplars) is influenced by blocked versus randomized conditions of presentation for target phonemes. During blocked presentation, exemplars for a target phoneme (i.e. /b/) appear in a “blocked” format (i.e. /bat/, /bam/, ban/). Random presentation may instead intersperse presentation of exemplars for various phonemes (i.e. /mad/, /bop/, /net/) throughout treatment. While Wambaugh et al. (2004) proposed that errors were more consistent during blocked presentation in a single participant with apraxia of speech and aphasia, group analysis by Mauszycki et al. (2010) again found that neither the blocked nor random presentation conditions influenced predictability of errors over time. This further highlights the inherent variability that may exist between individuals with apraxia of speech and the lack of any one, agreed upon pattern of performance for all individuals who exhibit this disorder due to methodological differences across studies.

In effect, it appears that ongoing lack of agreement in the literature may be attributed to differing methods of error analysis (individual versus group). As previously noted, among recent studies which propose that errors in apraxia of speech may be consistent and predictable for specific phonemes (Wambaugh et al., 2004; Mauszycki et al., 2007), observations were made regarding a single speaker with apraxia of speech and aphasia. Furthermore, intra-individual variability in these studies for error type across phonemes ranged from 0 to 58% (Wambaugh et al., 2004) and 0 to 25% (Mauszycki et al., 2007), respectively. These rates appear to coincide with early research by LaPointe and Horner (1976), who observed average variability (percent of repeated productions which differed from the preceding response across 10 repetitions of the same word) of 23-50% across seven subjects with apraxia of speech and aphasia. In turn, it is possible that variability at the individual level may occasionally go unrecognized in group analysis (Mauszycki et al, 2010). This possibility considered, these studies also highlight the danger of attributing specific deficits and patterns of performance (i.e. consistency of errors) in single subjects to all individuals with apraxia of speech.

The working definition of “consistency” itself has also continued to evolve. In some studies, this has been quantified as the degree of consistency in error type and location across successive, repeated productions of the same target word (Johns & Darley, 1970; LaPointe & Johns, 1975; McNeil et al., 1995). Mloch et al. (1982) investigated consistency in the productions of various target words across successive repetitions of sample readings. Mauszycki et al. (2007) examined error patterns for target phonemes across various exemplars (i.e. consistency of errors for the /b/ sound across exemplars, /bat/, /bad/, and /ban/). Still others have examined consistency of errors for specific phonemes across various target words over time (Mauszycki et al., 2010; Mauszycki and Wambaugh, 2006). Thus, methodological differences in measuring “consistency” of errors make it difficult to define general patterns of performance in apraxia of speech.

These conflicting findings cannot be directly compared of course, due to notable differences in comorbid diagnoses among sample participants and methods of speech elicitation across studies. However, ongoing debate over the presence of error inconsistency in apraxia of speech perhaps defines just what recent efforts have tried to clarify, predict, and better understand – the very presence of error inconsistency within and between speakers with apraxia of speech. That is, individuals with apraxia of speech may indeed evidence greater difficulty – or selective impairments – in certain motor programs, and in turn greater predictability of errors across successive repetitions and over time. However, it does not appear that these selective differences occur predictably and reliably for the same phonemes across individuals. Moreover, despite suggestions that inconsistent errors may be limited, inconsistent performance on other phonemes may evidence inadequate, but not absent motor programs for these additional speech sounds. Data is needed to definitively answer these questions.

The possibility that error consistency may be a defining characteristic of apraxia of speech has important clinical implications. Mauszycki et al. (2010) reported that patterns of predictable errors may allow for more efficient and focused treatment approaches, e.g. training phonemes that are predominantly produced with errors. Wambaugh, Kaylinyak-Fliszar, West, and Doyle have applied these principles to treatment approaches for apraxia of speech, using phonemes which are consistently in error as treatment stimuli (1998). Despite improvements for a restricted set of trained phonemes, overgeneralization, or production of trained sounds in place of untrained sounds has been reported (Raymer, Haley, & Kendall, 2002; Wambaugh, Martinez, McNeil, & Rogers, 1999). Therefore, considering the likelihood that errors may instead be largely inconsistent both within and across individuals, treatment across a broad range of phonemes may be warranted.

As proposed by Mauszycki et al. (2010), practice with specific, problematic phonemes may foster skills for creating and accessing novel oral motor programs for those phonemes which may be consistently in error. Yet additional practice with phonemes which are produced correctly and unpredictably on occasion may allow the refinement of existing, but inadequate motor programs for phonemic errors which are inconsistent on repeated attempts. By training sensorimotor and tactile kinesthetic features of a broad range of phonemes, this type of treatment may facilitate skills for identifying perceptual and production differences between sounds which vary slightly in both place (/b/ versus /t/) and manner (/b/ versus /p/) of production. Further, extensive motor practice with multiple phonemes during phonological awareness/processing, as well as segmenting and blending activities may additionally train skills for selecting appropriate motor sequences and self-correcting production errors. Such explicit training may decrease the potential for overgeneralization.

While error patterns may be expected to change following intervention and inform methods for evaluating treatment outcomes, there have been no studies to date examining change in patterns of error consistency for untrained target words following a broad, multimodal treatment of phonemes. Therefore, the purpose of the present study was to examine change in the number and location of errors across repeated productions of the same utterance, and examine change following a multimodal treatment in participants with apraxia of speech and aphasia.

Multimodal Intensive Treatment (MMiT) in Apraxia of Speech

MMiT Overview

During prior intervention efforts for adults with phonological alexia enrolled in a Multimodal intensive Treatment (MMiT), subjective changes were observed in participants' verbal praxis (Conway, et al., 1998; Kendall, et al, 2003; 2006; 2008). MMiT is based on a treatment program that was originally designed to train phonological awareness, reading, spelling and speech in children and adults, and later modified to retrain similar aspects of language and speech in adults with phonological alexia (Conway et al., 1998). Treatment follows a neurodevelopmental model, hierarchically training speech and language skills based on the typical sequence of acquisition for individual phonemes in children (Alexander & Slinger, 2004). As this treatment involves the integration of both language perception and processing skills as well as sensorimotor practice, it was therefore proposed that MMiT might jointly improve features of both speech and language components of communication.

On examining differences in performance based on mode of stimulus presentation, Johns and Darley (1970) demonstrated that participants were able to produce more accurate articulations when visual monitoring was combined with auditory stimuli, versus either stimulus mode alone. Likewise, MMiT involves training multimodal features of phonemes and feedback of performance throughout levels of instruction. The multimodal features include opportunities for visual and auditory modeling by the therapist, feedback and comparison activities, and exercises to develop phonological awareness, as well as motor practice and implementation of these learned skills. These activities may in turn develop learned associations between phonemes, novel phoneme sequences and their relevant motor programs. Further, MMiT uses pseudowords (phoneme combinations that follow English conventions but have no semantic meaning) as target words for treatment. This allows participants to practice various phoneme combinations without added demands on, or aid from lexical or semantic processing networks.

MMiT also advocates semi-random versus blocked practice of phonemes. Random practice of various phonemes and phonemic sequences has previously been shown to improve production and enhance retention of treated phonemes in individuals with apraxia of speech and aphasia (Knock, Ballard, Robin, & Schmidt, 2000). Thus, phoneme groups are introduced during Stage I of MMiT one at a time, and practiced until mastery before a new set of phonemes is introduced. As additional groups are incorporated into treatment, all phonemes introduced to that point are practiced randomly.

MMiT Stages of Treatment

Stages of treatment for MMiT are hierarchically organized, and require mastery of each stage before progressing to subsequent levels. This ensures a strong foundation for higher-level principles in more advanced stages of treatment. Stages of treatment progress as follows:

Stage I – Multimodal discovery of phonemes

Training associations between visual, auditory, oral kinesthetic, oral tactile, & metalinguistic features of phonemes using verbal labels (i.e. “lip popper” for /p/)

Stage II – Train phonological awareness

Phonological problem-solving tasks where participants must identify a single change between two pseudowords in a series (e.g. a change of phoneme number, order, or identity by adding, omitting, substituting, shifting, or repeating phonemes)

Stage III – Train generalization

Generalization training of Stage II phonological awareness to reading (blending phonemes) and spelling (segmenting pseudowords) accuracy, and self-correction of errors during these tasks

MMiT is heavily guided by methods of Socratic questioning during each stage of treatment, in which participants are questioned regarding the accuracy of their productions. By encouraging participants to attend to various aspects of speech, this method of questioning promotes skills for self-monitoring and correction. Therapists may provide statements which provide auditory feedback and opportunity for comparison, such as, “What I heard you say was /p/. Does /p/ sound like /k/?” This technique also provides visual information by allowing participants to compare the position of their mouth with a mirror, to that of their therapist. Further, sensory feedback may be provided, in which the participant must discriminate between various aspects of production, e.g. voiced versus unvoiced sounds (identified as “quiet” versus “noisy”). Finally, the manner of production (movements required for transitioning between sounds) may be examined through extensive practice with a variety of phoneme combinations and techniques for identifying sensation within the articulators during rapid movement from one sound to the next. Together, these training activities may help develop skills for novel oral motor programming.

The present study sought to answer the following research questions with respect to the multimodal treatment:

- Research Question 1: Does MMiT generalize to improved accuracy of productions during repetition of untrained real words?
- Research Question 2: Does MMiT reduce inconsistency in the total number of errors across successive repetitions of the same target word?
- Research Question 3: Does MMiT increase consistency of error location across successive repetitions of the same target word, and are errors consistent in location across sessions?

- Research Question 4: Is treatment progress related to the degree of improvement on measures of error consistency?

- Research Question 5: Do changes in language impairment relate to the degree of improvement on measures of error consistency?

CHAPTER 2
METHODS

Study Design

This project was appended to an ongoing study of MMiT in phonological alexia, a post-stroke reading disorder. Measures of apraxia of speech were therefore added to existing measures of language perception and production to further examine treatment outcomes for apraxia of speech following this intervention. This was a single-subject repeated measures design, with replication across three participants with apraxia of speech and aphasia. Treatment was provided two to four hours per day, over four to five days per week, over approximately 12 weeks, incorporating a total of 120 hours of MMiT per participant.

Study Inclusion and Exclusion Criteria

Participants were recruited through existing resources in the Brain Rehabilitation Resource Center (BRRC) of the Malcom Randall VA Medical Center, which have been well-established for an ongoing study of phonological alexia, a post-stroke reading impairment. To ensure that the period of spontaneous recovery had subsided, all participants were at least 6-months post-stroke at the time of enrollment. Participants were not diagnosed with depression or other psychiatric illness, degenerative neurological illness, chronic medical illness, and/or severely impaired vision or hearing, which might compromise their ability to understand and adhere to treatment demands.

Participant Demographics

Participants were three right-handed, monolingual English speakers who presented with left hemisphere stroke (see Figure 1-1.) and comorbid aphasia. Participant demographic information is shown in Table 1-1.

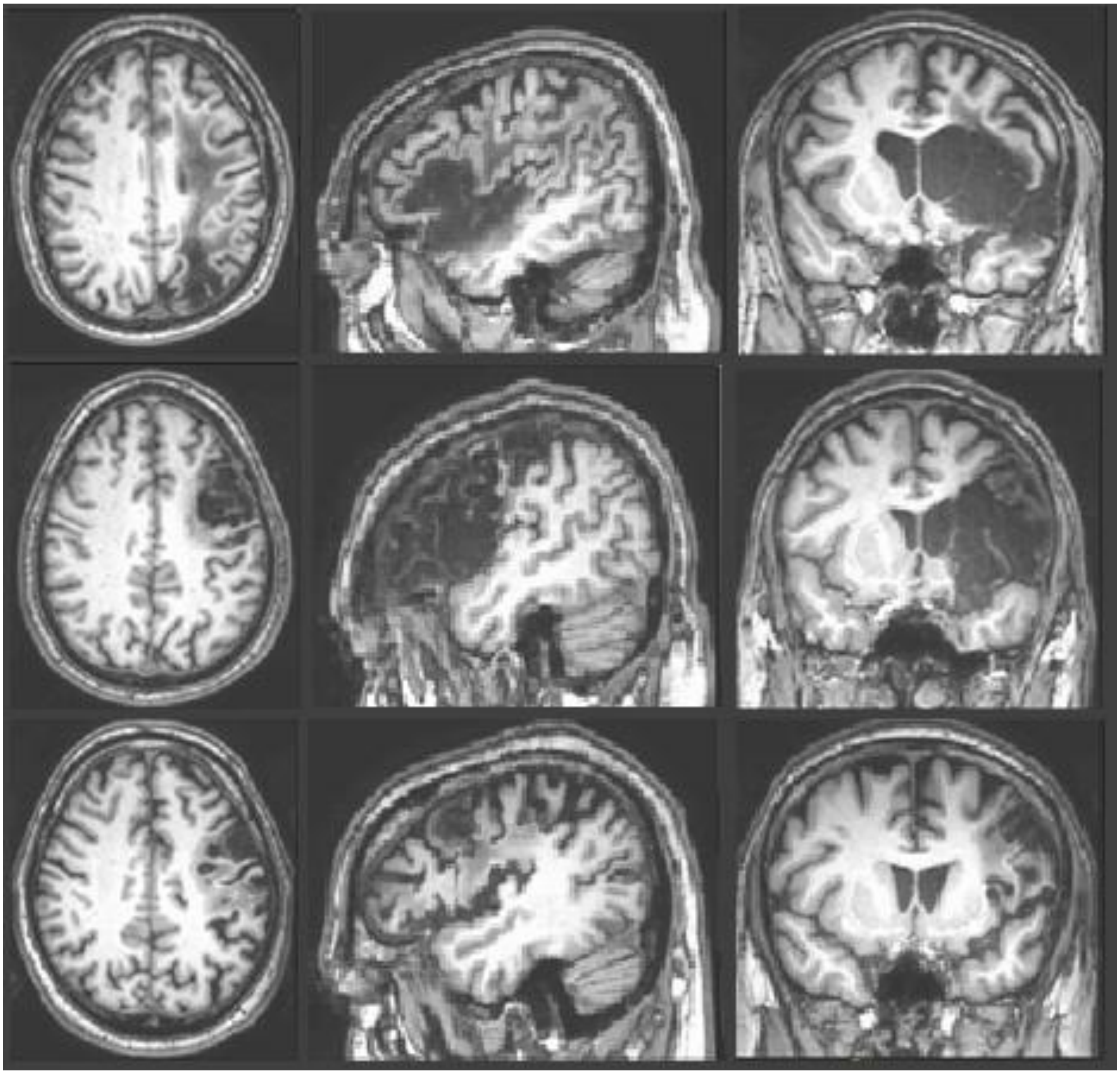

Figure 1-1. Magnetic resonance images for Participant1 (top row), Participant2 (middle row), and Participant3 (bottom row).

Table 1-1. Participant demographic information

	Age	Gender	Education (years)	Time Post Onset (months)
Participant 1	60	M	15	113
Participant 2	43	M	12	19
Participant 3	60	M	16	12

Apraxia of Speech Diagnosis

All three participants had a diagnosis of apraxia of speech as documented in their initial BRRC speech-language and behavioral neurology screening. Once participants met initial study criteria, we administered the Apraxia Battery for Adults, second edition, (ABA-2) (Dabul, 2000) to document severity of a range of features associated with apraxia of speech and to elicit profiles of individual participant deficits. The ABA-2 is a normed and standardized clinical measure, designed to provide a rough estimate of severity for a range of features implicated in apraxia of speech. Severity ratings for ABA-2 subtests are listed in Table 1-2.

Table 1-2. ABA-2 subtest severity ratings

ABA-2 Subtest	Participant 1	Participant 2	Participant 3
Diadochokinetic Rate	Mild	Mild	Mild
Increasing Word Length - A	Mild	None	None
Increasing Word Length - B	Severe	Moderate	Moderate
Limb Apraxia	None	None	None
Oral Apraxia	None	None	None
Latency and Utterance Time	Severe	None	None
Repeated Trials	Moderate	Moderate	Mild

An expert speech-language pathologist (SLP) with more than 35 years of experience in speech-language pathology and extensive work in the field of apraxia of speech research was blinded to outcomes on ABA-2 measures confirmed apraxia of speech diagnosis for all three participants. This diagnosis was confirmed using audio-recorded speech samples from select ABA-2 subtests.

Participant Speech Characteristics

In addition to meeting perceptual criteria as defined by ABA-2 severity scores, Participant1 also demonstrated visible and audible “searching” behaviors during speech production (unsuccessful attempts at finding the appropriate oral motor position to produce a target sound), numerous and varied off-target productions of target phonemes, increasing number of phonemic (sound-level) errors with words of increased length and complexity, difficulty initiating speech, and an awareness of errors but inability to self-correct. Participant2 also demonstrated visible and audible searching behaviors, increasing number of phonemic errors with words with increased length and complexity, and fewer errors in automatic versus volitional speech. Participant3's speech was additionally characterized by visible and audible searching behaviors, numerous and varied off-target productions of target phonemes during speech, difficulty initiating speech, fewer errors in automatic versus volitional speech, and an awareness of errors but inability to self-correct.

Assessment of Comorbid Language Disorders

Degree of comorbid language impairment was obtained with the Western Aphasia Battery (WAB) (Kertesz, 1982). WAB scores and aphasia classification are listed in Table 1-3.

Table 1-3. Western Aphasia Battery total scores and classification

	Participant 1	Participant 2	Participant 3
Fluency (max 20)	13	14	17
Comprehension (max 10)	7.4	9.55	10
Repetition (max 10)	7.10	8.5	9.4
Naming (max 10)	4.8	7.2	8.6
Aphasia Quotient (max 100)	64.6	93.2	90
Aphasia Classification	Anomic	Anomic	Anomic

Note:
Totals listed for participants on WAB subtests are weighted raw scores
Aphasia Quotient – Weighted composite of subtest scores on the *Western Aphasia Battery* indicating overall severity of language impairment; a score of 100 indicates no impairment; scores of 93.8 and higher are considered normal.
Anomic aphasia is characterized by scores of 5-10 on Fluency, 7-10 on Comprehension, 7-10 on Repetition, and 0-9 on Naming, as demonstrated in all three participants.

Assessment of Comorbid Motor Speech Disorders

To account for possibly comorbid motor speech disorders, the Motor Speech Examination (MSE, see Freed, 2000) and a lab-developed measure of sensory awareness (titled, “Subjective Ratings of Sensory Awareness”; see Appendix) were administered to determine the possible presence and severity of dysarthria. The MSE is a clinician rating tool designed to evaluate the integrity of the mouth and facial muscles first at rest (i.e. presence of droop or asymmetry in the tongue, lips, or face), then during non-speech oral movement (i.e. range and amplitude of motion in lips, tongue, etc.), and finally during speech (i.e. phonation). The lab-developed “Subjective Ratings of Sensory Awareness” questionnaire allows participants to provide subjective reports of change in oral sensation and motor control. Results from these measures are listed in Table 1-4.

Table 1-4. Assessment of comorbid motor speech disorders

	Participant 1	Participant 2	Participant 3
MSE Summary	Mild deviation of mouth to the right (mandible, tongue) and deviation of mouth during production of /e/ sound	Mild deviation of tongue to right; weak glottal stop, cough	Mild breathiness, harshness, and pitch breaks during phonation
Subjective Ratings of Sensory Awareness	No Subjective loss of sensation; some difficulty controlling muscles in lips, inadequate jaw strength during biting (while eating only)	No Subjective loss of sensation; difficulty closing right eye completely, no difficulty projecting voice or producing sufficient speaking volume	Reduced sensation in right cheek/neck/inner ear, problems winking right eye; no noticeable problems in or around mouth

The Limb and Oral Apraxia subtest of the ABA-2 was also administered to determine the presence and severity of limb apraxia and oral apraxia in the context of apraxia of speech. These subtests measure the accuracy and control of various non-speech oral and limb movements (stick out your tongue, throw a ball, etc.). None of the three participants demonstrated measurable deficits for limb or oral apraxia on these subtests.

Dependent Measure

We administered the Repeated Trials subtest of the ABA-2 at pre- and post-treatment as the dependent variable. In this task, participants are asked to repeat an aurally presented target word three times in succession (i.e. “computer, computer, computer”) for a total of ten items. Severity scores are determined by the total number of words without error. Variability scores may also be calculated to demonstrate change in total number of errors across successive repetitions of each target word.

Phonetic Transcription

Audio recorded speech samples for the Repeated Trials subtest of the ABA-2 were broadly transcribed by a trained transcriptionist who was blinded to assessment time points, using the International Phonetic Alphabet. Due to the need for qualitative assessment of speech characteristics for adequate transcription, the identity of the participants could not be masked on audio recorded speech samples. The transcriptionist was however, blinded to treatment progress, pre-treatment speech and language assessment profiles, and other information relevant to each participant’s unique profile of performance.

Two Ph.D.-level speech-language pathologists (SLPs), blinded to participant identities and time points used transcriptions to rate total number and location of errors on each of three repeated responses for all 10 target words. This included other disrupted speech behaviors and signs of abnormal prosody (i.e. false starts, perseverations, incorrect stress assignment). A third, blinded SLP provided a consensus rating for discrepant ratings (participant responses which were rated differently by the two primary SLPs).

Rater Reliability

Reliability of transcription ratings was calculated as percent agreement in the total number of errors for each session, location of errors (percent of phonemes scored as incorrect by both raters), and item-to-item agreement (percent of all target words which matched in both number and location of errors for both raters).

Total Number of Errors

To answer Research Question 1 (do treatment effects generalize to accuracy of productions during repetition of untrained real words?), the total number of errors was calculated before and after MMiT. This was totaled across all 30 responses (three repetitions for each of 10 target words) for each participant. Change following MMiT (increase or decrease in the total number of errors) was then determined. It was expected that following MMiT, participants would be more accurate in their productions and therefore produce fewer errors at post-treatment.

Total Error Inconsistency across Repetitions

To answer Research Question 2 (does MMiT reduce inconsistency in the number of phonemic errors across successive repetitions?), a variation of Cohen's *d* was used (Busk & Serlin, 1992) to measure effect size for change in the total number of errors for each response. As noted by Beeson and Robey (2006) this variation may be calculated with representative data points (i.e. target words within a session) as a measure of change in untrained items. Effect Size was calculated as follows:

$$d_1 = \frac{\bar{x}_{A_2} - \bar{x}_{A_1}}{S_{A_1}}$$

where A_1 and A_2 represent the standard deviation (SD) for the total number of errors across successive repetitions for each target word during pre- and post-treatment periods, respectively. S_{A1} is the standard deviation of calculated SD values across all target words at pre-treatment. Standard deviation was calculated for each target word, and the average was calculated in this way to determine an overall inconsistency score for each participant and time point. This value could then be compared between pre- and post-treatment for the evaluation of change and effect size. Effect sizes for change in each participant's inconsistency score were classified as small (.2 to .5), medium (.5 to .8) and large (>.8) (Cohen, 1988). It was expected that following MMiT, participants would be more consistent in their productions across successive repetitions. In turn, inconsistency scores (change in the number of errors across successive repetitions of each target word, as measured by change in the average standard deviation across all target words) would be reduced.

Consistency of Error Location

Research Question 3 (does MMiT increase consistency in error location within and between sessions?) was performed to replicate and extend previous research on typical patterns of "error consistency" in apraxia of speech (see McNeil et al., 1995). This former study suggested that individuals with "pure" apraxia of speech who demonstrate a production error on a given phoneme are likely to demonstrate errors in the same word location (or on the same target phoneme) on subsequent responses of the same target word. “Consistency of error location,” as described by McNeil and colleagues therefore refers to the percentage of phonemic (sound-level) errors which occur repeatedly across successive repetitions of the same target word. This is calculated for given phonemes within each target word, as oral motor demands may differ based on surrounding phonemes. For example, the /m/ sound in “motorcycle” places a different set of oral motor demands on the range and accuracy of movement than the /m/ in “computer.”

Consistency within sessions

To answer the first part of Research Question 3 (does MMiT increase consistency in error location within sessions?), consistency of error location within a session was calculated. This was achieved by first totaling the number of phonemic errors present across all 30 responses (three repetitions for each of 10 target words). Next, phonemic errors occurring two or three times on the same target phoneme across the three repetitions of a target word (i.e. errors which were “consistent in location”) were totaled. Overall consistency in error location for the session was calculated as total number of “consistent” errors divided by total phonemic errors present across all 30 responses (three repetitions for each of 10 target words).

For example, in the target word “computer,” a participant may respond, “womputer, computer, fumputa.” For this target word, there are three phonemic errors (/w/, and /f/ in the initial position and /a/ in the final position). Of those three phonemic errors, two occur for the same phoneme across the three repetitions (/w/ and /f/ in place of the first phoneme). Therefore, for this first target word, two phonemic errors are “consistent” in error location. Overall consistency of error location is therefore calculated at 66.7%. This example is illustrated in Figure 2-1 below.

Target word	**computer**
Repetition 1	**w**omputer
Repetition 2	computer
Repetition 3	**f**omput**a**
Total # of consistent errors	2
Total # of errors	3
Consistency of error location	66.7%

Figure 2-1. Example of consistency of error location within sessions

Consistency across sessions

To answer the second part of Research Question 3 (does MMiT reveal consistency in error location between sessions?), consistency of error location between sessions was obtained. This was performed as an extension of previous research to further compare performance before and after MMiT. First, the total number of errors present in the same word location (for the same phoneme) at both time points was totaled. This was then divided by the total number of phonemic errors produced during both pre- and post-treatment. For instance, the presence of an error for a target phoneme during any of the three successive repetitions at one time point would be considered to be consistent across sessions if it was also present during the other time point. An example of this calculation is illustrated for one target word in Figure 2-2 below. In this example, the /a/ produced in place of the final phoneme for “computer” is considered consistent across sessions, as it appears for at least one repetition at pre-treatment and also for at least one repetition at post-treatment. This measure provides an estimate of error predictability for certain phonemes over time.

	Pre-treatment	Post-treatment
Target word	**computer**	**computer**
Repetition 1	**w**omputer	comput**a**
Repetition 2	computer	comput**a**
Repetition 3	**f**omput**a**	comput**a**
	Total # of consistent errors	4
	Total # of errors	6
	Consistency across sessions	66.67%

Figure 2-2. Example of calculation for overall consistency of error location across sessions

Treatment Progress

To answer Research question 4 (does treatment progress predict degree of improvement on measures of error consistency?), time spent in each stage of treatment and highest levels of training achieved were recorded for each participant. This was intended to highlight potential patterns of performance based on progress through treatment. It was expected that participants who spent less time in initial stages of oral awareness training and advanced to more complex stimuli through treatment would also demonstrate more accurate and consistent performance on measures of error consistency at post-treatment.

Language Improvement

To answer Research question 5 (does improvement on measures of language impairment predict degree of improvement on measures of error consistency?) measures of phonological perception and production were administered at pre- and post-treatment. This was measured via the Lindamood Auditory Conceptuallization Test, third edition (LAC-3) (Lindamood & Lindamood, 2004) and the Comprehensive Test of Phonological Processing (CTOPP) (Wagner et al., 1998) for phonological perception and production, respectively. Additionally, the WAB AQ was acquired at post-treatment to determine change in overall severity of aphasia.

It was expected that participants who demonstrated more severe language impairment at pre-treatment, as evidenced by lower scores on these measures, might also demonstrate a greater number of total errors at both time points. Additionally, it was proposed that greater language impairment might influence participants' ability to cognitively target and manipulate motor components of speech during MMiT; therefore, it was expected that these participants would also demonstrate poorer performance on measures of error consistency (greater inconsistency in both number and location of errors across successive repetitions of the same target words) at both time points. Finally, it was expected that participants who demonstrated gains on language measures would also demonstrate gains on measures of consistency in error location and number across successive repetitions of the same target words.

CHAPTER 3
RESULTS

Rater Reliability

Percent agreement for error ratings on the Repeated Trials subtest was calculated at 96% for total number of errors. Agreement in error location (percentage of phonemes scored as incorrect by both raters) was 95%. Raters demonstrated 91% overall item-to-item agreement.

Total Number of Errors

Research Question 1 asked whether MMiT would generalize to accurate production during repetition of untrained real words. Indeed, total number of errors produced across all 30 responses decreased from pre-to post-treatment assessment for Participant1 (65 to 38) and Participant2 (14 to 7). Participant3 did not show this reduction, demonstrating a total of 5 errors at both pre- and post-treatment. Thus, MMiT did generalize to accurate productions during repetition of untrained words for two participants.

Error Inconsistency across Repetitions

Research Question 2 asked whether MMiT would reduce inconsistency in the number of errors across successive repetitions of the same target word. Indeed, Participant1 showed reduced error inconsistency (change in total number of errors across successive repetitions of target words) from .58 to .40, (Cohen's d =.24, small effect). Participant 2 showed a reduction from .39 to .06 (Cohen's d = .78, medium effect). Participant3 also demonstrated a reduction from .23 to .12 (Cohen's d = .39, small effect). Thus, all three participants showed a treatment effect for reduced error inconsistency across repetitions, as expected.

Consistency of Error Location

Research Question 3 asked whether MMiT would increase consistency in error location (percentage of errors occurring on the same target phoneme within a target word, across more than one repetition) within and between sessions.

Consistency within Sessions

All three participants demonstrated increased consistency of error location at post-treatment. While participants showed a large range in performance at pre-treatment (40-77%), a smaller range was demonstrated at post-treatment (60-86%). These data are shown in Figure 2-1. Thus, following MMiT, all participants showed increased consistency of error location and also a smaller range in performance was seen across participants.

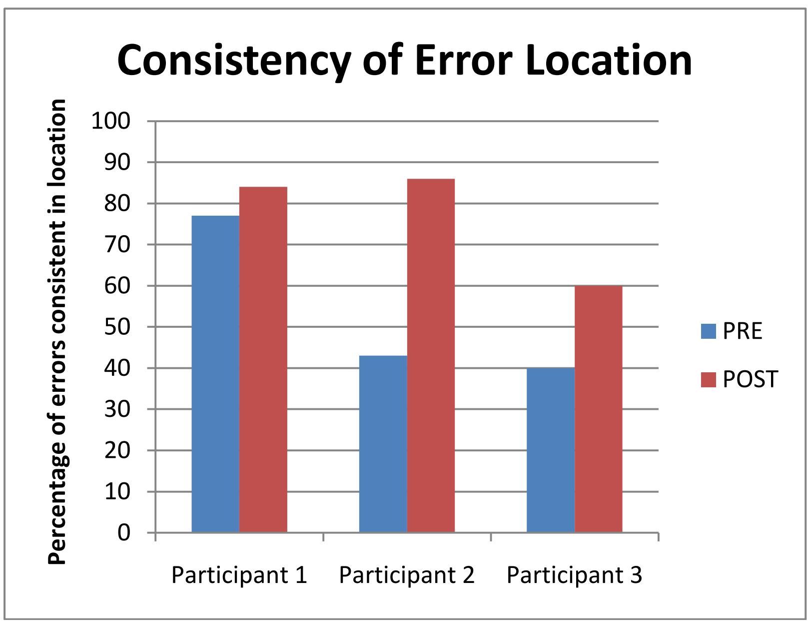

Figure 2-1. Consistency of error location for all three participants at pre- and post-treatment

Consistency across Sessions

Measures of consistency in error location across sessions (total percentage of phonemic errors which were present on a given sound segment at both pre- and post-treatment) revealed that 25% of Participant1's speech errors, produced across pre- and post-treatment time points, occurred consistently in the same location within a target word. Thirty-eight percent of Participant2's errors occurred in the same location, across pre- and post-treatment time points. None of the errors produced at post-treatment for Participant3 were consistent across both time points. Thus, a relatively small percentage of total errors at both time points were specific to a certain phoneme. This was seen across all three participants.

Treatment Progress

Research Question 4 asked whether treatment progress was related to degree of improvement on measures of error consistency. All three participants demonstrated consistent progress throughout MMiT's hierarchy of stages and difficulty levels within a stage.

Greatest Level Achieved

Participant2 and Participant3 achieved the same maximum phoneme combination for single syllable pseudowords during training and the same maximum number of syllables for multisyllable pseudowords. Participant1 achieved a slightly reduced maximum number of phonemes for single syllable pseudowords, but did not progress to the multisyllable pseudowords level of training in MMiT.

Partcicipant1, who reached the least complex levels of practice for pseudoword stimuli also demonstrated the greatest number of errors at pre- and post-treatment. While this participant also demonstrated the weakest gains in consistency of error location from pre- to post-treatment, he also demonstrated the greatest initial level of consistency in error location at pre-treatment.

Time Required for Each Treatment Stage

Participant1 took slightly more time to complete oral awareness training and spent the majority of treatment in training simple syllable phonological processing, reading and spelling. In comparison, Participant3 completed simple syllable training quite readily, spending the majority of time with more complex syllable words. Unfortunately, treatment data for Participant2 was not available for review for simple stages of syllable production during MMiT due to a therapist error with treatment records. However, it appears that Participant2 spent more time in more advanced stages of treatment with complex syllable pseudowords relative to Participants 1 and 2. Time to complete each stage of treatment and maximum level of training achieved are listed in Table 2-1.

Table 2-1. Treatment hours completed and maximum levels of stimuli achieved

	Participant 1	Participant 2	Participant 3
Oral Awareness Training	5	-	4
CV/VC/CVC Treatment	115	-	29
Complex Syllables (CCV/VCC/CVCC/CCVC/ CCVCC)	0	74	51
Greatest number of phonemes	3-phonemes	4-phonemes	4-phonemes
Greatest number of syllables	None	5-syllable pseudowords	5-syllable pseudowords

Notes:
CV – Consonant-Vowel – Pattern denotes complexity of phonemic combinations for pseudoword stimuli
Greatest number of phonemes – Number of phonemes incorporated into target items during pseudoword segmenting and blending activities, for single-syllable pseudowords only
Greatest number of syllables – Total number of syllables incorporated into multisyllable pseudoword targets

Language Improvement

Research Question 5 asked whether improvements on language measures predicted degree of improvement on measures of error consistency. All three participants showed modest, but measurable improvements on each of three measures of language, including overall severity, phonological perception, and phonological production. Pre- and post-treatment scores for all three participants are listed in Table 2-2.

Table 2-2.Language measure outcomes

	Participant 1	Participant 2	Participant 3
WAB AQ - pre	64.6	93.2	90
WAB AQ - post	65.6	94.8	91.8
LAC-3 - pre	55	59	63
LAC-3 - post	62	76	85
CTOPP - pre	55	52	55
CTOPP - post	58	61	58

Notes:
WAB AQ – Aphasia Quotient from the Western Aphasia Battery; max 100
LAC-3 – Standard scores on the Lindamood Auditory Conceptualization test, third edition
CTOPP – Standard scores on the Comprehensive Test of Phonological Processing

CHAPTER 4
DISCUSSION

Despite a wealth of studies measuring error consistency within target words and across repeated sampling occasions in adults with post-stroke apraxia of speech, there have been no studies to date examining change in error consistency following a multimodal treatment for a broad range of phonemes, including phonemes that may or may not be produced in error prior to treatment. Thus, it was proposed that MMiT, which trains distinctive sensory and motor features of phonemes through problem-solving activities (phonological processing, phoneme blending, and phoneme segmenting) with pseudowords (phoneme sequences that follow the linguistic conventions of English, but do not have a semantic meaning) might improve the accuracy and/or consistency of repeated productions of real words in adults with post-stroke apraxia of speech. Therefore, the purpose of the present study was to examine change in error patterns following MMiT in a sample of participants with post-stroke apraxia of speech and aphasia.

Research Question 1: Generalization to Accuracy of Productions

It was proposed that through semi-random practice of a broad range of phonemes and implementation of learned phonological principles through various oral motor speech tasks, MMiT might increase the accuracy of phoneme production. Indeed, improved accuracy of productions for two participants during the repetition of untreated, real word stimuli appears to provide initial support for treatment generalization. As these words were not directly trained during MMiT, improvements may reflect participants' ability to accurately identify phoneme combinations in target words, and access oral motor plans and sequences necessary to accurately say a target word. Thus, it appears that following MMiT, participants may apply skills targeted during activities with pseudowords (phoneme combinations with no semantic meaning) to real word stimuli as well.

It appears that by targeting only those phonemes which are consistently in error prior to treatment, response generalization to untrained sounds remains limited (Wambaugh et al., 1998, Raymer et al., 2002), despite benefits for the production of phoneme exemplars (words that contain the target phoneme). In turn, these findings support an approach which targets a broad range of phonemes through a variety of novel phoneme combinations, thereby allowing participants to integrate skills for blending and segmenting phonemes to untreated words for phonemes which may or may not be consistently in error prior to treatment. While the present investigation did not control for level of exposure or continued practice outside of treatment with the specific real words used during the Repeated Trials task, these results offer preliminary support for the generalization of MMiT to real word repetition. Follow up studies may examine the ecological validity of the repetition task, and the possible relationship to additional measures of real world communication.

Research Question 2: Error Inconsistency across Repeated Productions

Beyond measures of overall improved accuracy, this project sought to examine the influence of MMiT on error inconsistency in the total number of phonemic errors produced across repetitions. Indeed, it appears that MMiT may reduce inconsistency across repeated productions of the same utterance. Improvements in these participants indicate that following MMiT, successive repetitions within an item are produced more similarly amongst each other than at pre-treatment. This may suggest that once individuals have selected an appropriate motor program, they are better able to maintain the selected motor sequence across repeated productions of the same word. Despite a similar direction of change, the participant with the smallest relative treatment effect for reduced error inconsistency also presented with a high initial severity of apraxia of speech and aphasia, and consequently, relatively limited gains during MMiT. Additionally, improvements in error inconsistency may have been obscured by the far greater number of errors present at both pre- and post-treatment in this participant, compared to others in the sample. In turn, gains in the production of certain target words may have been largely obscured by ongoing phonemic errors within other words in the target series.

Research Question 3: Consistency of Error Location

Consistency within Sessions

Measures of consistency in error location were calculated to determine the predictability of errors for specific phonemes within target words. This measure was intended to replicate and extend previous findings conducted in speakers with “pure” apraxia of speech (McNeil et al., 1995). Following MMiT, gains were observed for increased consistency of error location in all participants. This uniform direction of change appears to suggest that while participants are generally more accurate in their productions and produce fewer phonemic errors overall, the explicit and broad phoneme and word-level training in MMiT (including a problem-solving approach to phonological processing, reading and spelling) may have trained the participants in a structured and systematic approach to word production overall. In turn, phonemic errors at post-treatment appear to be more predictable for certain speech sounds across repeated, oral productions of words following intervention.

Interestingly, results from this analysis appeared to diverge somewhat from previous work by McNeil et al. (1995). In this prior investigation, four speakers with “pure” apraxia of speech demonstrated errors which were 90% consistent in error location, with a small range (86-94%). In contrast to these findings, results from the present investigation demonstrated average consistency in error location for participants of about 53.3% prior to treatment, with a fairly large range (40-77%). Following MMiT, while results were more consistent in error location for all three participants, they still presented with a lower average consistency of about 72.7% and range of 60-86%.

Divergent findings may relate to the use of a “pure” apraxia of speech sample in this former study, and the potential influence of comorbid language and motor speech deficits in the participants examined in the present investigation. Therefore, while this study was not able to replicate previous findings, it instead provides preliminary evidence of patterns of error consistency for participants with apraxia of speech and aphasia. Further, it provides evidence of change in this error pattern following intervention.

Consistency across Sessions

It has been suggested that the presence of consistent phonemic errors across time may reflect specific oral motor programming deficits for certain phonemes (Mauszycki et al., 2010). However, it appeared that a relatively small proportion of phonemic errors were present within a given word at both time points in this study. This appeared to reflect both a decrease in the total number of phonemic errors at post-treatment (few pre-treatment errors remained for specific phonemes following intervention overall) and also the unexpected introduction of “consistent” errors across multiple productions of the same target word at post-treatment (consistent errors of production for phonemes produced correctly prior to intervention).

Inconsistency in error location across sessions in this case may also reflect the intervening role of MMiT in participants' approach to word production. Through extensive oral awareness training and methods of guided questioning during treatment, participants are routinely instructed to consider the way their mouth is positioned while they produce each phoneme, and thoughtfully plan the necessary sequence of movements before an attempt is made. This may alter their approach to real word combinations of phonemes, and may evidence some degree of overgeneralization of the treatment approach (Raymer et al., 2002; Wambaugh et al., 1999). In effect, while MMiT trains participants to apply skills for self-monitoring and correction to phonemes which are produced in error, participants may apply this approach to the production of all phonemes, whether or not oral motor programs for those phonemes are already well-established. This study does not have data to determine the exact nature of errors that appeared for phonemes which were produced correctly prior to treatment. However, it does suggest that the intervention may have resolved some specific motor programming deficits for the majority of phonemes (as evidenced by fewer errors overall at post-treatment).

Research Question 4: Treatment Progress and Improved Consistency

To determine the degree of improved consistency based on progress through treatment, hours spent in each level of treatment and highest level of training achieved for pseudoword stimuli was determined for each participant. Interestingly, while gains were observed for increased consistency of error location in all participants following treatment, the participant who demonstrated the least treatment progress also showed the greatest consistency in error location at both pre- and post-treatment. This observed error pattern is particularly surprising in light of previous findings from Mloch et al. (1982), who found that consistency in the misarticulation of certain words, but not for specific phonemes, was associated with greater severity of apraxia of speech.

However, findings must be considered in light of concurrent improvements in overall level of phonemic accuracy. In turn, a high degree of consistency in error location for a participant with substantially more errors might highlight the presence of consistent deficits for an extensive range of phonemes. In contrast, fewer “inconsistent” errors at post-treatment and the potential role of a more systematic approach to word production in less impaired individuals may instead reflect treatment benefit. Therefore, while increased consistency of error location for a small subset of remaining errors may reflect overall improved oral motor programming, those who progress slowly through treatment and continue to demonstrate a large number of errors may evidence ongoing deficits for motor programming and production.

Research Question 5: Language Improvement and Improved Consistency

The participant who was most impaired at pre-treatment on measures of aphasia severity (as evidenced by comparatively lower WAB, LAC-3, and CTOPP scores) also demonstrated the least treatment progress. On measures of accuracy and consistency across repeated productions, this participant demonstrated the greatest number of phonemic errors at both time points, and the smallest relative treatment effect for decreased error inconsistency across repetitions. These findings highlight the likely role of initial language impairments in the degree of treatment progress, as well as on measures of accuracy and consistency of productions following treatment.

Following MMiT, all participants improved on all three language measures. Concurrent improvements for all individuals on both the LAC-3 and CTOPP also demonstrate improved phonological processing at the level of both perception (identifying features and differences between phonemes) and production (with added demands of executing motor programs when producing words or pseudowords). These changes were seen along with increased consistency of error location for all participants, and a decrease in total number of errors. Again, one participant did not show concurrent improvements in language and the total number of errors produced, which may have been due to near-ceiling performance prior to treatment.

In turn, improvements in both language function and consistency of repeated real word productions suggest that as language impairment begins to resolve, residual motor programming deficits may become more apparent, and therefore more easily targeted in therapy. Likewise, if MMiT were modified for the treatment of apraxia of speech rather than phonological alexia, it might initially train improved phonological processing for all phonemes, as currently employed in MMiT for phonological alexia. Following these initial stages, it might then explicitly target oral motor production and practice for a broad variety of combinations for target phonemes. Extensive oral motor practice with a variety of exemplars (various phoneme combinations which include the target phoneme) during treatment has shown benefits for the production of phonemes trained specifically during therapy (Wambaugh et al., 1998). Thus, this added component of treatment may provide a range of oral motor practice for a broad range of phonemes in the context of many different surrounding phonemes.

Influence of Comorbid Language and Motor Speech Disorders

As noted earlier, several additional language and motor speech disorders must be considered in relation to changes seen for patterns of error consistency following MMiT. Oral apraxia, or deficits in oral motor control for non-speech oral movements is one motor speech disorder which may influence treatment outcomes. While this may not be expected to impact performance on measures of word repetition as evaluated by dependent measures, oral apraxia may influence participants' ability to adhere to task demands, particularly during initial oral awareness training in MMiT, Stage I. As this stage involves extensive oral-motor instruction (i.e. "lift your tongue, pucker your lips, touch the roof of your mouth, etc.) difficulties in this area may limit speakers' ability to acquire the necessary skills for more advanced stages of treatment. Based on outcomes from the Oral Apraxia subtest of the ABA-2 at pre-treatment evaluation however, it appears that none of the participants in this sample experienced deficits that might impair performance during treatment (Table 1-2.) and at least two of the participants advanced through oral awareness training within the first four to five hours of treatment. In turn, it is unlikely that oral apraxia contributed significantly to initial patterns of error consistency in number and location, as none of the participants demonstrated oral apraxia deficits at a measurable level.

Dysarthria, a motor speech disorder due to neuromuscular weakness or incoordination, may present more similarly to apraxia of speech during performance on dependent measures (multiple repetitions of real words). Some mild dysarthria appeared evident for all three participants, as evidenced by some observed deviation of the articulators at rest and some observed abnormalities during phonation. None of the participants in this sample endorsed subjective loss of sensation in or around the mouth, which presumably allowed for unhindered completion of Stage I Oral awareness training during MMiT.

It should be noted that one participant did endorse experiencing some difficulty controlling the lip muscles and some reduced jaw strength while eating. Additionally, this participant demonstrated the most severe apraxia of speech and language impairment at pre-treatment, and fewer gains on measures of error consistency. However, low consistency of error location for this participant across sessions suggests that errors were not produced exclusively for specific phonemes. As observed by McNeil et al. (1995), participants with dysarthria appear to show a high degree of consistency in error location across repeated productions of the same target words. In contrast, the participants in the present study demonstrated a relatively low percentage of errors which were consistent for specific phonemes across both pre- and post-treatment time points. Thus, the pattern of errors observed for participants in the current study suggest that phonemic errors were likely not due exclusively to comorbid dysarthria. While this provides evidence for persistent deficits in the production of certain phonemes within a session for participants with dysarthria, this prior study did not examine production across repeated sessions. Therefore, the extent to which dysarthria contributed to changes in error consistency in the current sample appears minimal, but cannot definitively be ruled out at this time.

Comorbid aphasia, or language impairment, may also have contributed to resulting patterns of speech errors. Likewise, McNeil et al. (2008) have suggested that initial reports of error inconsistency in apraxia of speech may have resulted from the inclusion of individuals who actually demonstrate phonemic paraphasias. Phonemic paraphasias are productions which are largely intelligible, but may include various substitutions, omissions, and transpositions of phonemes which differ within the target word – for example, producing "nap" for "ban" (Goodglass, Kaplan, & Barresi, 2001). While often perceptually similar to apraxia of speech, phonemic paraphasias may reflect language-level disturbances in the selection of target phonemes versus deficits in motor programming for an intact phonological sequence (Mauszycki et al., 2010).

While this variability may arguably be attributed to comorbid aphasia diagnoses, it appears that the degree of variability is not clear even within samples of "pure" apraxia of speech. McNeil et al. (1995) reported consistency in error location and type with little intra-individual variability for specific phonemes across successive item repetitions. This was noted in contrast to observed inconsistency in error location across successive repetitions across four participants with conduction aphasia. However, while certain words may also be consistently in error across successive contextual readings in those with "pure" apraxia of speech, there remains great variability in the specific errors produced within each word and word location (Mloch, et al., 1982).

The extent to which aphasic impairments may have contributed to observed error patterns was examined in this study using pre-treatment evaluations for aphasia severity and classification. WAB scores in turn revealed classification of anomic aphasia for all three participants. Largely intact ability on Repetition in this battery argues strongly against a diagnosis of conduction aphasia, as examined by McNeil and colleagues in relation to "pure" apraxia of speech. Furthermore, conduction aphasics examined in McNeil's study demonstrated mostly word-level versus sound-level errors. None of the participants in this study demonstrated word-level errors during the

Repeated Trials task, providing further support for the presence of a predominant phonetic-motoric impairment versus linguistic deficiency during pre- and post-treatment performance on the dependent measure (McNeil et al., 1995).

As phonemic paraphasias may be features of a variety of aphasic syndromes, the possibility remains that these types of language-level errors may have occurred to some extent in the present sample. However, as previously mentioned, “pure” apraxia of speech is extremely rare (Duffy, 2005) and it is therefore difficult to generalize findings in these limited studies to most clinical populations. Therefore, while this project accounts for the nature of some presenting errors, overall it contributes to a growing understanding of typical patterns of error production in a clinically relevant sample and demonstrates the impact that MMiT may have on speech and language deficits.

Limitations

For purposes of this preliminary investigation, broad phonetic transcription was employed to first determine the potential for change in error consistency following MMiT. Findings from this level of error analysis provide preliminary support for post-treatment improvement in consistency of speech productions in this sample. However, narrow transcription may provide additional information on error type (specifically differences between errors of substitution and distortion) and provide data on the variability of productions for specific phonemes within and between sessions. Generalization of findings is limited by the small sample size and limited number of words for measurement of word repetition. Future work may consider selecting test stimuli based on the frequency of occurrence for various phonemes (Mines et al., 1978), and ensure a broad range of phoneme combinations for testing. Finally, findings are limited to isolated repetition of real word stimuli, and may not equate to performance variability in other contexts, such as reading or spontaneous speech. Despite study limitations, this investigation reveals post-treatment changes in error patterns on a measure typically used in clinical settings to guide treatment plans (ABA-2).

Future Directions

Together, these findings further reveal the inherent variability that may exist within and between individuals with apraxia of speech. This is evidenced by observed differences within and among participants in this study and the influence of individual participant qualities (i.e. treatment progress and initial severity of speech and language impairments) on treatment outcomes for dependent measures. Moreover, these findings demonstrate the necessity and value of a single-subject research designs in this population. As highlighted by Mauszycki et al. (2010), group analysis may overshadow important differences that might exist between individuals in the total number and location of errors produced across repeated sampling sessions. In turn, future research may investigate error analysis at both group and individual levels to better characterize patterns of error inconsistency between and within speakers with apraxia of speech.

In summary, these results support subjective reports of improved verbal praxis following MMiT and suggest it may improve the consistency and/or accuracy of speech in adults with post-stroke apraxia of speech. Additional participant and follow-up data is needed to determine the influence of MMiT on additional features of apraxia of speech, maintenance of observed gains, and patient-specific characteristics which might influence treatment outcomes. Lastly, if MMiT is implemented to solely treat apraxia of speech, then several modifications to the treatment approach seem relevant to consider. A modified version of the MMiT for apraxia of speech may involve the following treatment components:

1) Broad, multimodal training for phonological processing and perception

2) Extensive, semi-random oral motor practice with a broad range of phonemes

3) Semi-random practice of trained phonemes within a greater number of exemplars (phoneme combinations which incorporate the target phoneme for training) and various speech production contexts (repeated productions of the same target word, words of increasing length, spontaneous and automatic speech, etc.)

4) Tracking treatment outcomes through additional measures of oral motor production and generalization

APPENDIX: SUBJECTIVE RATINGS OF SENSORY AWARENESS

1. Are there any areas of your face where you feel less sensitive to touch, temperature, or pain?
2. Are there any areas of your face where it is more difficult for you to control your muscles?
3. Do you find it hard to make certain facial movements?
    a. Smiling
    b. Laughing
    c. Showing someone you are angry
    d. Opening your eyes widely
    e. Puckering your lips
4. Do you have any difficulty biting, chewing, or otherwise moving your jaw?
5. Do you find it difficult to keep your teeth strongly clenched?
6. Is it hard for you to keep your jaws or lips together when you are not eating or speaking?
7. Can you feel your tongue against the roof of your mouth?
8. Can you feel your tongue between your teeth?
9. Can you feel your tongue between your lips?
10. Can you feel your tongue against the inside of your cheek?
11. Do you have any difficulty drinking or swallowing?
12. Is it difficult for you to produce the volume of sound that you would like?
13. Do you find it difficult to project your voice?

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BIOGRAPHICAL SKETCH

Dana Szeles graduated with honors from the University of Connecticut in 2007 with a B.S. in cognitive neuroscience. Her senior thesis was conducted in the Behavioral Neuroscience lab at UConn under the direction of Dr. Roslyn Holly Fitch, and explored recovery from auditory processing deficits in an animal model of hypoxia-ischemia. Following graduation, she worked for two years as a clinical research assistant at the Olin Neuropsychiatry Research Center in Hartford, Connecticut, studying fMRI of major depressive disorder in adolescents and adults.

Dana is now a neuropsychology graduate student in the Department of Clinical and Health Psychology at the University of Florida, studying under the direction of Dr. Tim Conway in the Brain Imaging Rehabilitation and Cognition lab. She is interested in the progression and course of recovery for individuals with acquired language and motor speech disorders. She is currently working on a project through the Brain Rehabilitation Research Center at the Malcom Randall VA Medical Center exploring patterns of brain reorganization in phonological alexia using fMRI. Through this experience, she has also been able to work closely with Dr. Stacy Harnish and other experts in speech and language pathology exploring change in apraxia of speech following language intervention. Dana completed her M.S. in the spring of 2011 through the Department of Clinical and Health Psychology at the University of Florida.