Introduction

Acquired apraxia of speech (AOS) is typically described as a disorder of motor control. Specifically, AOS is believed to result from impaired motor plans/programs for speech production (McNeil, Robin, & Schmidt, 1997). However, there is some disagreement surrounding the underlying cause of AOS (Code, 1998; Dogil& Mayer, 1998; Dogil, Mayer & Vollmer, 1994). This controversy may be influenced by the fact that AOS, which commonly results from left hemisphere stroke, often co-occurs with aphasia. Therefore, it is difficult to isolate impairments resulting from disruption of the motor plan/program and impairments of the language system. Consequently, traditional treatments for AOS have been motivated by the symptoms of the disorder, not the theoretical concept of the underlying impaired mechanism. In more recent studies however, researchers have begun to focus treatment on the impaired motor plan/program (Austermann Hula, Robin, Maas, Ballard & Schmidt, 2008; Ballard, Maas & Robin, 2007; Knock, Ballard, Robin & Schmidt, 2000).

The treatment employed in this Phase II study adds to a growing body of literature that uses schema theory (Schmidt, 1975) and principles of motor learning (PML; Schmidt, 1988) as the theoretical framework to rehabilitate impaired planning/programming mechanisms in individuals with AOS (Austermann et al., 2008; Ballard, Maas & Robin, 2007; Knock et al., 2000; Maas et al., 2008; Schmidt & Lee, 2005). Schema theory supports the idea that motor learning of trained skills occurs through practice and experience, whereas PML provide instructions for the conditions of practice and types of feedback thought to support generalization and retention of learned skills.

The primary aim of this study was to employ an intensive treatment founded on schema theory and PML to a single individual with severe AOS. To that end, the following research questions were posed: (1) Does treatment improve repetition of trained sounds in isolation? (2) Does treatment generalize to untrained sounds in isolation? (3) Does treatment improve production of trained sounds in real and nonwords? (4) Does treatment improve production of untrained sounds in real and nonwords? (5) Does treatment generalize to a measure of ecologic validity? And (6) does treatment aid in long-term retention of learned skills?

METHODS

Participant: The participant was a monolingual English speaking, right –handed, 38-year-old male who suffered a left cerebral vascular accident (CVA) 22 months prior to initiation of this study. He presented with severe apraxia of speech as evidenced by visible and audible articulatory searching and groping behaviors during individual word repetition, difficulty initiating speech, sound distortions, sound substitutions perceived as being distorted, voicing errors, and varied off-target attempts at a sound or word. The *Apraxia Battery for Adults—Second Edition* (ABA-2; Dabul, 2000) revealed non-speech oral-motor performance to be characteristic of severe non-verbal oral apraxia and limb apraxia. In addition to AOS, the participant demonstrated aphasia characterized by significant expressive and receptive language deficits. To quantify nature and severity of aphasia, the *Western Aphasia Battery* (WAB; Kertesz, 1982) and *Boston Naming Test* (BNT; Kaplan, Goodglass & Weintraub, 1983) were administered (see Table 1).

Design: A single-subject ABA repeated-probe design with pre- and post-treatment testing was employed. Prior to initiation of treatment, five baseline data points were established. The treatment phase was followed by three sessions of immediate post-testing and three sessions of maintenance testing, after a two-month delay. A quality of life measure and a measure of communicative abilities were administered to determine if any effects generalized to functional level abilities (Table 1).

Procedures: Treatment was administered two hours/day, four-days/ week over the course of six weeks, for a total of 48 hours. The treatment program was comprised of two stages. Stage 1 trained selected phonemes in isolation and Stage 2 trained 1 syllable real and non-words. In Stage 1, each phoneme was trained by teaching motor descriptions (e.g., the lips come together and pop apart), production (e.g. repeat after me…say /b/), perceptual discrimination (e.g., do we sound the same?) and grapheme to phoneme correspondences (e.g. letter for each sound is displayed). Stage 2 was an extension of Stage 1, including combinations of various phonemic sequences (e.g. CV, VC, CVC). PML known to enhance generalization and retention of trained skills were incorporated into each stage of treatment.

Stimuli: Treatment stimuli were selected using the challenge point framework (Guadagnoli & Lee, 2004; Mass et al., 2008) and criteria thought to prevent overgeneralization of treated sounds (Raymer, Haley & Kendall, 2002; Ballard et al., 2007). Phonemes were selected based on patient stimulability. To prevent overgeneralization, a large stimuli set was trained and varied across manner, place and voice. Selection of generalization stimuli was based on schema theory and PML, in which trained skills (sounds) are hypothesized to generalize within manner and across place (Mass et al., 2008). To investigate transfer of trained skills to untrained real and nonwords, additional generalization stimuli were constructed using trained and untrained phonemes (Table 2).

Outcome Measures

Research questions #1-4 were answered through analysis of repeated probes. Research question #5 was addressed by a quality of life measure and a measure of communicative abilities administered pre and post treatment. Research question #6 was answered by analysis of repeated probes two months post treatment. All repeated probe data were analyzed in terms of effect sizes (ES) (Beeson & Robey, 2006).

RESULTS

Research question #1 addressed acquisition effects of treatment on improved sound production for trained sounds (Figure 1, Graph A). Results showed a medium effect size.

Research questions #2-4 were directed toward generalization of treatment to repetition of untrained sounds (Figure 1, Graph A), real and nonwords containing trained sounds (Figure 1, Graph B), and real and nonwords containing untrained sounds (Figure 1, Graph C). Repetition of untrained sounds showed a small effect size, real and nonwords comprised of trained sounds showed a small effect size and repetition of real and nonwords comprised of untrained sounds showed no effect size.

Research question #5 (Table 1) asked if effects of treatment would generalize to a quality of life measure and a measure of communicative abilities. No significant changes to the communication domain of the quality of life rating scale were observed. A notable increase in the area of social communication on the measure of communicative abilities was evident.

Research question #6 (Figure 1, Graph A, B & C) looked at maintenance of treatment and generalization effects two months post treatment termination. Trained sounds were found to have a large effect size, untrained sounds showed a medium effect size, real words comprised of trained sounds showed a medium effect size, nonwords comprised of trained sounds showed a small effect and real and nonwords comprised of untrained sounds showed no effect. The control probe data (Figure 1, Graph D) showed no effect.

DISCUSSION

The current study was a Phase II investigation designed to test the effects of a phonomotor treatment program founded on schema theory and PML on the rehabilitation of AOS. Presence of treatment effects was evident and is supported by schema theory. We believe that through experience and practice our participant's capability to produce skilled movements necessary for speech production improved. Furthermore, presence of generalization and maintenance effects was evident and is theoretically supported by PML. Specifically, we attribute these results to the conditions of practice and frequency of feedback employed in this study.

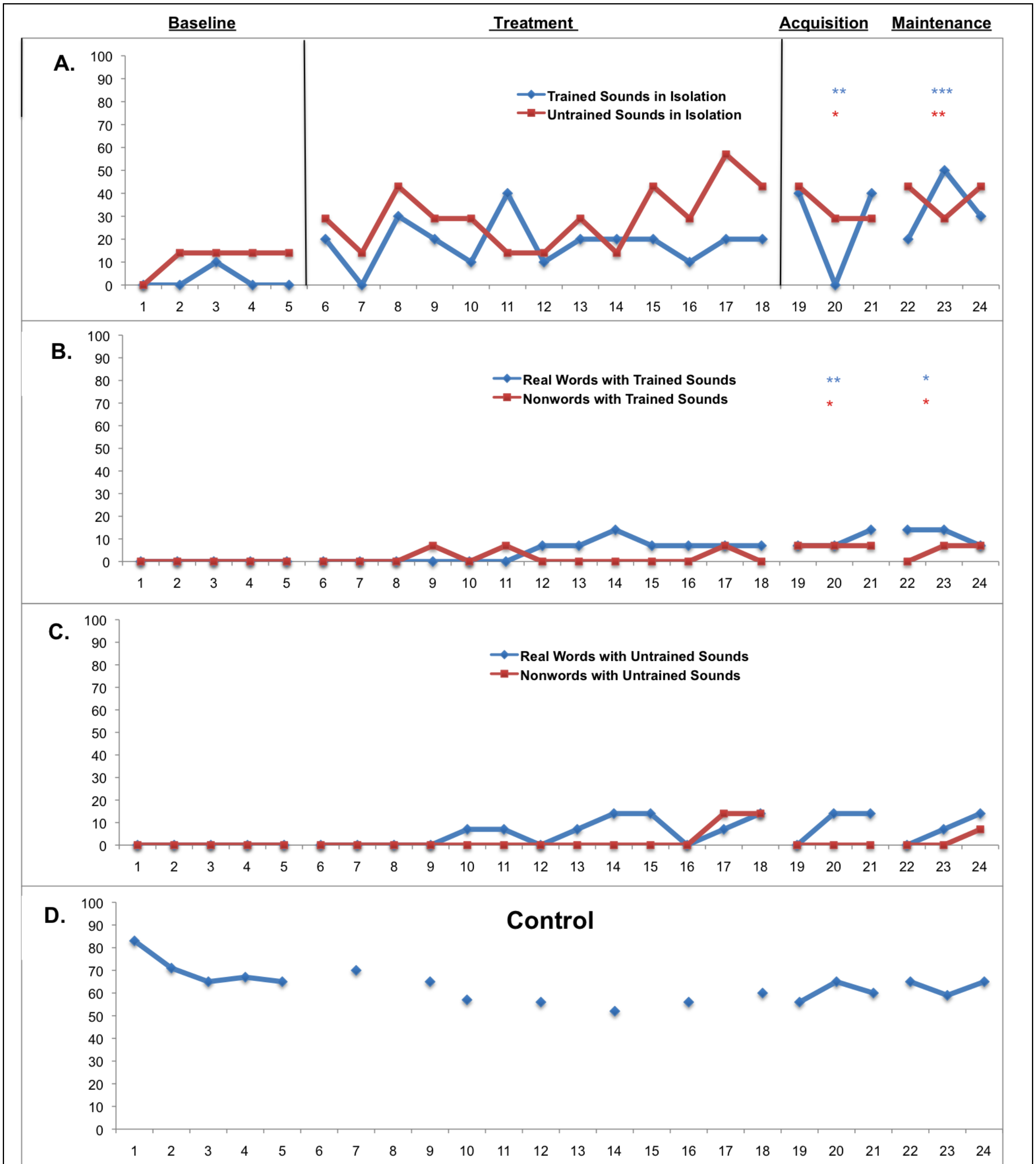

Figure 1. Baseline, Treatment, Generalization and Two-month Maintenance Effects. A) Trained and Untrained Sounds in Isolation, B) Real and Nonwords made up of Trained Sounds, C) Real and Nonwords made up of Untrained Sounds, D) Control measure, The Five-Point Test (Ruff, 1988).

* indicates a small effect size

** indicates a medium effect size

*** indicates a large effect size

Table 1. Standardized pre and post test scores

1. Western Aphasia Battery (WAB; Kertesz, 1982), 2. Boston Naming Test (BNT; Kaplan, Goodglass & Weintraub, 1983), 3. Apraxia Battery for Adults-Second Edition (ABA-2; Dabul, 2000), 4. Stroke and Aphasia Quality of Life Scale – 39 item version (SAQOL-39; Hilari, Byng, Lamping & Smith, 2003), 5. American Speech-Language-Hearing Association Functional Assessment of Communication Skills (ASHA FACS; Fratalli, Holland, Thompson, Wohl & Ferketic, 1995)

	Pre	Post 1	Post 2
1. WAB **Aphasia Quotient** (Total possible points =100)	14	16	21
2. BNT (Total possible points = 60)	0	0	0
3. ABA-2			
1. Diadochokinetic Rate	**	**	**
2a. Increasing word length	**	**	**
2b. Increasing word length	**	**	**
3a. Limb apraxia	21 severe	26 moderate	32 moderate
3b. Oral apraxia	11 severe	18 severe	18 severe
4. SAQOL-39 (1-5 rating, 5 indicating no difficulty) *Communication domain*	3.56 *1.86*	NA	2.91 *1.86*
5. ASHA FACS (Total possible points =147)	75	NA	103

Pre =before treatment initiation
Post-1=immediately post treatment termination
Post-2=four months post treatment termination
** could not perform due to apraxia severity
NA = data was not collected on this measure

Table 2. Repeated Probe Stimuli	
Trained Sounds	/b, θ, v, ʃ, n, t, z/ /i, ɑ, u/ ◆
Untrained Sounds	/p, ð, f, ʒ, m, d, s/ ◆ +
CVC Words with Trained Sounds	
Real Words	/buθ/, /bɑt/, /tuth/, /tiz/, /θot/, /θiz/, /zuz/, /ʃiv/, /ʃɑt/, /nɑb/, /nun/, /niz/, /tub/, /tin/
Nonwords	/bɑz/, /tiv/, /vut/, /θin/, /zɑʃ/,/ʃun/,/niv/,/nub/, /ʃɑθ/,/zut/, /θɑb/,/vin/,/tɑθ/, /biʃ/
CVC Words with Untrained Sounds	
Real Words	/dum/, /dip/, /puf/, /pis/, /fid/, /fud/,/suð/, /sɑd/, /sim/, /mɑp/, /mɑs/, /mus/, /pɑp/, /dip/
Nonwords	/diʒ/, /pum/, /fɑp/, /ðid/, /sɑf/, /ʒum/, /mis/, /mɑʒ/, /ʒɑd/, /sith/, /ðɑs/, /fip/, /pum/, /dup/

◆ indicates stimuli were selected based on challenge point framework (Guadagnoli & Lee, 2004)

\+ indicates stimuli were selected based on Schema Theory and PML (Mass et al., 2008)

Table 3. Effect Size for Repeated Probes

Stimuli		Effect Size	
		Post 1	Post 2
Trained			
	Trained Sounds	5.52**	7.01***
Generalization			
	Untrained Sounds	3.59*	4.33**
	CVC Words with Trained sounds		
	Real Words	1.73	3.53*
	Nonwords	0.43	1.70
	CVC Words with Untrained Sounds		
	Real Words	0.0	1.43
	Nonwords	0.0	0.83
Control			
	Five Point Test (Ruff, 1988)	-1.30	-.95

Post-1 = immediately post treatment termination (acquisition)
Post-2 = Two-months post treatment termination (maintenance)
d ES 2-4 = small, 4-6 = medium, > 6 = large (Robey et al., 1999)
* indicates a small effect size
** indicates a medium effect size
*** indicates a large effect size