Introduction

While there is a range of treatment approaches for AOS, there are few well-controlled treatment efficacy studies [1]. Those that have examined response generalization or long-term retention have reported varied success [1, 2]. This study presents a treatment for improving control of voicing for plosives and af/fricatives, based on principles of motor learning and designed to maximize generalization and long-term learning.

Control of voicing for accurate production of consonants is a complex skill requiring fine control and coordination across several articulators [3-5]. This presents particular difficulty for individuals with AOS. To retrain the ability to manipulate voicing for voiced versus voiceless phonemes, it is proposed that selected stimuli need to provide multiple contrasts along this dimension; intensive training on multiple phonemes should increase the likelihood of acquisition and subsequent generalization to improved production of voiced / voiceless contrasts in untrained consonants. This approach is akin to the varied practice principle of motor learning (PML) advocated by Schmidt & Lee (1999).

Several studies have directly examined the application of PML in the speech system [6-9]. These have demonstrated that, similar to limb systems, performing skills in random order, with a high number of practice trials and delayed, low frequency feedback on accuracy (i.e., knowledge of results, KR) tends to promote long-term retention and/or generalization of treatment effects to novel behaviors. Furthermore, Schmidt & Lee [10] argued that presentation of feedback on performance, or how a movement was executed (e.g., biofeedback), is potentially important but only in the initial phase of treatment.

We tested the hypotheses that varied practice of voicing control (i.e., training multiple sounds) within manner with random order of stimulus presentation and delayed low frequency KR feedback will result in (a) generalization of treatment effects to voiced phonemes of same manner, (b) no deterioration in accuracy of voiceless phonemes of same manner, typically produced with high accuracy, (c) no change in accuracy of voicing for phonemes of a different manner, and (d) retention of treatment effects 2 months post-treatment.

Methods

Subjects

The study included two male American-English speakers (P1: 56 yrs, P2: 42 yrs) with impaired control of voicing for plosives, fricatives, and affricates. P1 demonstrated mild-moderate AOS and minimal dysnomia secondary to left hemisphere cerebrovascular accident; P2 demonstrated severe AOS with moderate Broca's aphasia secondary to focal traumatic brain injury (Table 1).

Experimental Design

Multiple baselines across subjects and behaviors designs were employed to examine acquisition, generalization, and retention of behaviors. P1 received 3 baseline tests, P2 had 4 tests. Treatment was continued until trained behaviors reached 80% accuracy over 3 consecutive sessions or 15 sessions were completed. Retention was probed to 3 months post-treatment.

Probes

The baseline tested ability to produce voiced and voiceless cognates as well as continuous voicing from a preceding vowel into the voiced phoneme. Production of 15 'b', 15 'g', 15 't', 5 'p', 5 'k', 5 'd', 15 'v', 15 'dj', 15 's', 5 'f', 5 'ch', and 5 'z' initial words was tested in a carrier sentence (P1) or phrase (P2). All responses were elicited with orthographic stimuli and no modeling from the clinician. No feedback on performance or accuracy was provided.

Four (P1) to five (P2) experimental probes, identical to baseline, were administered at equal intervals throughout the treatment phase. These tested for generalization of treatment effects to untrained phonemes of same and different manner.

Treatment

P1 was trained on the phonemes 'v', 'dj', and 's' in a carrier sentence; P2 was trained on 'b', 'g', and 't' in a carrier phrase. Sessions were structured according to the procedures of PML [10]: each session involved a pre-practice period, akin to traditional therapy, and a practice period applying PML. In pre-practice, phonetic placement cues [7, 11] and spectrographic feedback on timing of voicing were provided to define parameters of a correct response and elicit correct productions. Participants were trained in the first session to interpret a spectrogram of correct and incorrect productions of treated phonemes. Participants were encouraged to achieve continuous voicing for voiced phonemes. Practice involved eliciting the target phonemes in words in a carrier phrase / sentence in random order without examiner models 50 times each (150 trials / session). Knowledge of results (KR) feedback was provided on 60% of trials with a response-to-feedback delay of 3-4 sec. Provision of KR feedback was based on acoustic analysis of a real-time spectrographic display (CSL, Kay Elemetrics) hidden from the participant.

Responses to stimuli were transcribed online and audiorecorded for reliability. A correct response showed continuous voicing on voiced phonemes, voice onset time >40 msec for voiceless plosives, and no overlap of voicing and frication for a voiceless fricative.

Reliability

Inter-rater and intra-rater reliability were high on acoustic measures (i.e. dependent variables, $r > 0.90$) and on adherence to steps in the treatment protocol (i.e. independent variable, > 95%).

Results

All hypotheses were supported.

Trained Behaviors

Both participants acquired the ability to produce continuous voicing on the two trained voiced phonemes during treatment (data not shown) and demonstrated generalization of the treatment effect to the trained behaviors in the experimental probe (P1: 'v' $C = 0.67$, $p < 0.05$ and 'j' $C = 0.69$, $p < 0.05$; P2: 'b' $C = 0.86$, $p < 0.01$ and 'g' $C = 0.81$, $p < 0.01$) (Figures 1, 2).

Untrained Behaviors

The treatment effect generalized to untrained voiced phonemes of same manner (P1: 'z' $C = 0.63$, $p < 0.05$; P2: 'd' $C = 0.68$ $p < 0.05$) (Figure 1, 2). The effect is more clinically significant for P1 than P2. Accuracy of voiceless phonemes of same manner remained high throughout treatment. As predicted, neither subject demonstrated reliable improvement in production of continuous voicing for untrained phonemes of a different manner (P1: 'b' $C = 0.18$, $p > 0.05$, 'd' $C = 0.19$, $p > 0.05$, 'g' $C = 0.45$, $p > 0.05$; P2: 'v' $C = 0.09$, $p > 0.05$, 'z' $C = -0.35$, $p > 0.05$, 'j' $C = 0.29$, $p > 0.05$). P1 and P2 demonstrated retention of treatment effects above baseline levels.

Discussion

An approach for training control of voicing, based on principles of motor learning, was tested with an individual with pure AOS and one with AOS plus aphasia. The treatment was efficacious. Both participants learned to produce continuous voicing, suggestive of increased ease and fluency of production, or decreased segmentation. Both subjects rapidly learned to interpret a real-time spectrographic display of speech for biofeedback KP during pre-practice. This treatment approach, which included a voiceless phoneme in the treatment set, prevented deterioration in accuracy of voiceless phonemes of same manner. This indicates improved control over voicing for speech. Treatment effects generalized to increased accuracy of untrained related behaviors (i.e. sounds of same manner). Experimental control was maintained: sounds of a different manner showed no reliable improvement. Both participants retained treatment effects. Additional data are being analyzed (i.e., voice onset time of plosives, frication and voicing duration of af/fricatives, regardless of continuous voicing). Inter-rater reliability on provision of KR feedback during the practice, based on objective acoustic measures, was high. This method is desirable as it minimizes effects of perceptual drift and bias. Future studies should examine the ecological validity of this treatment approach.

References

1. Wambaugh, J. & Doyle, P. (1994). Treatment for acquired apraxia of speech: A review of efficacy reports. *Clinical Aphasiology*, *22*, 231-243.
2. Wambaugh, J. & Cort, R. (January, 1998). *Treatment for AOS: Perceptual and VOT changes in sound productions*. Poster presented at the Motor Speech Conference, Tucson, AZ.
3. Lisker, L. & Abramson, A. (1964). A cross-language study of voicing in initial stops: Acoustical measurements. *Word*, *20*, 384-422.
4. Löfqvist, A. & Yoshioka, H. (1981). Interarticulator programming in obstruent production. *Phonetica*, *38*, 21-34.
5. Gracco, V. & Löfqvist, A. (1994). Speech motor coordination and control: evidence from lip, jaw, and laryngeal movements. *Journal of Neuroscience*, *14*, 6585-6597.
6. Adams, S. & Page, A. (2000). Effects of selected practice and feedback variables on speech motor learning. *Journal of Medical Speech-Language Pathology*, *8*, 215-220.
7. Knock, T., Ballard, K., Robin, D. Schmidt, R. (2000). Influence of order of stimulus presentation on speech motor learning: A principled approach to treatment for apraxia of speech. *Aphasiology*, *14*, 653-668.
8. Maas, E., Barlow, J., Robin, D., Shapiro, L. (2002). Treatment of sound errors in aphasia and apraxia of speech: Effects of phonological complexity. *Aphasiology*, *16*, 609-622.
9. Austermann, S., Robin, D., Ballard, K., Maas, E., & Schmidt, R. (May, 2004). *Influence of feedback frequency on treatment for acquired Apraxia of Speech*. Clinical Aphasiology Conference, Park City, UT.
10. Schmidt, R. & Lee, T. (1999). *Motor control and learning*: *A behavioral emphasis*, 3rd Ed. Champaign, IL: Human Kinetics.
11. Van Riper, C. & Irwin, J. (1958). *Voice and articulation*. Englewood Cliffs, NJ: Prentice Hall.

Table 1. Results of diagnostic testing pre-treatment.

		Participant 1		**Participant 2**	
Western Aphasia Battery					
Aphasia Quotient	*(AQ /100)*	***97.2***		***51.3***	
Impairment severity		***Normal***		***Moderate***	
Spontaneous Speech	(/20)	**19**		**9**	
Information Content	(/10)	10		5	
Fluency	(/10)	9		4	
Comprehension	(/200)	**200**		**181**	
Yes/no Questions	(/60)	60		57	
Auditory Word Recognition	(/60)	60		56	
Sequential Commands	(/80)	80		68	
Repetition	(/100)	**98**		**38**	
Naming	(/100)	**98**		**38**	
Object Naming	(/60)	60		22	
Word Fluency	(/20)	18		5	
Sentence Completion	(/10)	10		5	
Responsive Speech	(/10)	10		6	
Reading	(/100)	**100**		**72**	
Reading Sentences	(/40)	40		34	
Reading Commands	(/20)	20		8	
Writing	(/100)	**87**		**58.5**	
Writing on Request	(/6)	6		6	
Written Output	(/34)	29		11	
Writing to Dictation	(/10)	8.5		1	
Psycholinguistic Assessment of Language Processing in Aphasia 2					
Same-Different Discrimination Using Word Minimal Pairs					
Total	(/36)	36		Not Tested	
Apraxia Battery for Adults – 2 (Raw score and Level of impairment)					
1. Diadochokinetic rate		18	Mild	1	Severe
2A. Increasing word length		9	Severe	8	Severe
2B. Increasing word length		1	None	Not Tested	
3A. Limb apraxia		48	None	48	None
3B. Oral apraxia		49	None	46	None
4. Utterance time for polysyllabic words		16	Mild	100	Severe
5. Repeated trials		19	Mild	Not Tested	
6. Inventory of characteristics (/15)		9	+ for AOS	12	+ for AOS

Figure 1. P1's accuracy in production of continuous voicing for trained and untrained behaviors in experimental probes during baseline, treatment, and retention phases of the study. A: Treated fricatives / affricates; B: Generalization to untreated fricatives / affricates; C: Control behaviors (plosives).

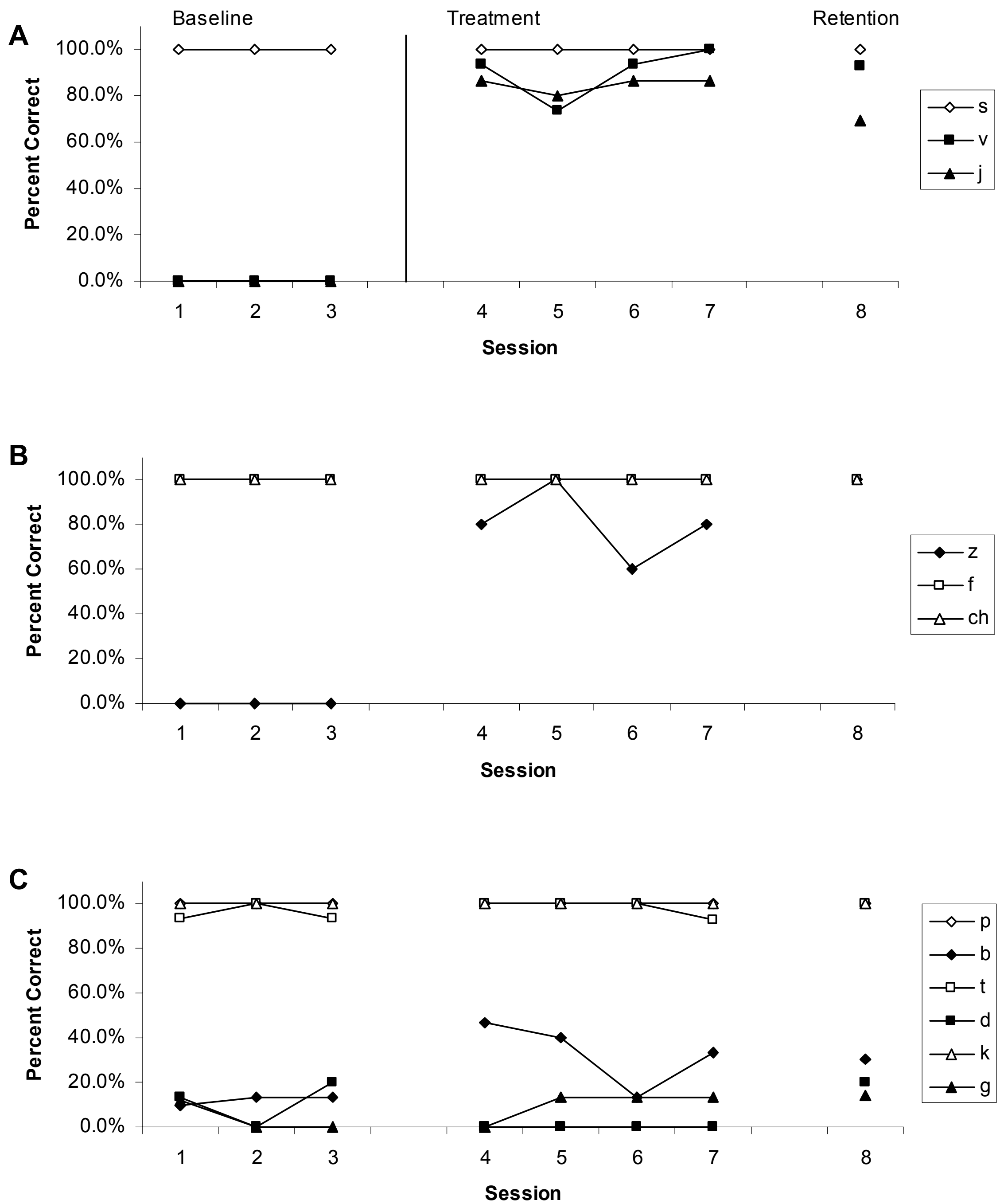

Figure 2. P2's accuracy in production of continuous voicing for trained and untrained behaviors in experimental probes during baseline, treatment, and retention phases of the study. A: Treated plosives; B: Generalization to untreated plosives; C: Control behaviors (fricatives / affricates).