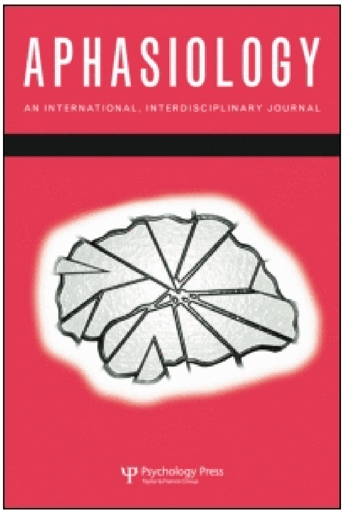

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Treating apraxia of speech (AOS) with EMA-supplied visual augmented feedback

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Treating apraxia of speech (AOS) with EMA-supplied visual augmented feedback

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Background: Previous studies have suggested that visual augmented feedback provided by electromagnetic articulography (EMA) helps persons with apraxia of speech (AOS) recover speech motor control following stroke (e.g., Katz et al., 2007). However, the data are few, both in terms of the variety of participants and the speech motor targets investigated.

Aims: This study was designed to determine whether EMA supplied feedback improves articulatory accuracy in an adult with acquired AOS. We also examined whether reduced feedback frequency results in (1) decreased performance during acquisition and (2) enhanced maintenance and generalisation of the targeted behaviours.

Methods & Procedures: A multiple-baseline across-behaviours design was used to assess the efficacy of this treatment for an individual with AOS. Over a 27-week period, the participant received visual feedback provided by an EMA system for treatment of three groups of speech motor targets (SMTs): /j/, /θ/, and /tʃ/ with various following VCs. The consonant clusters /br/ and /sw/ served as untreated controls. Frequency of feedback scheduling was 100% for /j/ and /tʃ/, and 50% for /θ/.

Outcomes & Results: For the first group of SMTs treated, /j/, there was acquisition for 4/5 trained words. These were maintained post-treatment and at the long-term probe. Improved performance and maintenance were also noted for 5/8 untreated stimuli, with maintenance shown for most of these words by 1 month post-treatment. The next treated SMT, /θ/, showed acquisition for all five treated items. Two of these five targets were maintained one month post-treatment. All three untreated /θ/ probes showed generalisation, with two of these showing maintenance post-treatment. The third treated group of SMTs, /tʃ/, showed improved performance for all of the five treated words. However, these gains could only be attributed to /tʃ/ treatment for three of the five words. Two treated items appeared well maintained at 1 month post-treatment. Generalisation and maintenance were also noted for all six untreated /tʃ/ words. However, generalisation from previously

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treated /j/ and /tʃ/ targets was involved in their improved performance. The untrained (control) word data suggested that the gains noted for treated items did not result from across-the-board improvement or unassisted recovery. There were no consistent differences corresponding with low- versus high-frequency feedback conditions.
Conclusions: Augmented kinematic feedback provided by an EMA system improved production for some, but not all, treated targets. Generalisation to untreated probes was also evident. Predictions concerning the effects of feedback frequency on the acquisition, maintenance, and transfer of trained behaviours were not supported.

Keywords: Apraxia of speech; Treatment; Electromagnetic articulography; Speech motor control; Feedback.

Apraxia of speech (AOS) is a speech motor deficit thought to involve motor planning (Van der Merwe, 1997) or planning / programming impairments (McNeil, Robin, & Schmidt, 1997). Although AOS has traditionally been considered difficult to treat, the application of motor learning principles to its treatment may provide new optimism for clinicians (see reviews by Ballard, Granier, & Robin, 2000; McNeil, Doyle, & Wambaugh, 2000).

A treatment method currently being explored involves providing augmented feedback of articulatory movements by means of an electromagnetic articulography (EMA) system. EMA is a non-invasive method for tracking speech movement (including the tongue) using low-strength magnetic fields. In this specialised clinical application, EMA is used to show a participant the position of the articulators during intended movements. The aim is to use visual feedback to clarify movement aspects of speech as a restitutive treatment for AOS and related disorders.

Two single-participant studies conducted in our laboratory have suggested that EMA can be used to treat speech motor deficits in individuals with Broca's aphasia and AOS. Katz, Bharadwaj, and Carstens (1999) explored EMA as a means of remediating fricative articulation deficits in the speech of a 63-year-old woman with Broca's aphasia and moderate-to-severe AOS. Over a 1-month period the participant was provided with (1) EMA visual feedback for tongue tip position during fricative production, and (2) foil treatment in which a computer program delivered voicing-contrast stimuli for simple repetition. The results suggested lasting improvement from the visually guided feedback, while the phonetic contrast treated in the foil condition showed only slight improvement, with a return to baseline 10 weeks later.

Katz, Bharadwaj, Gabbert, and Stettler (2002) investigated EMA therapy for a 67-year-old male talker with anomia and mild-to-moderate AOS. A similar experimental design was employed, with two error-prone groups of speech motor targets (SMTs) assigned to EMA treatment (/θ/, /tʃ/) and two assigned to a foil treatment condition. Treatment was provided bi-weekly for a 1-month period. The results of a perceptual assessment indicated that groups of SMTs treated with EMA were notably improved over baseline levels, while the groups of SMTs treated in the foil condition showed no evidence of improvement. The group of /θ/ SMTs was maintained 6 weeks post-training, while the group of /tʃ/ targets declined near baseline levels. Taken together, the data of these two studies suggest superior performance under EMA training for the small sets of SMTs investigated.

The theoretical underpinnings of EMA treatment derive from studies conducted in the framework of *schema theory*, an influential view of motor control and learning (Schmidt, 1975, 1976). Schema theory assumes that when individuals practise a particular class of movements they acquire a set of rules (or schema) that are used to determine the parameter values necessary to produce different versions of the action. Two key concepts in schema theory are *generalised motor programs (GMPs)* and *parameters*. GMPs contain invariant, abstract information about relative timing, structure, and force that allow an individual to produce different versions of a movement. Parameters are the values assigned to the GMP that allow individuals to adjust a movement pattern to meet specific environmental demands.

Schema theory makes an important distinction between the initial acquisition of a skill and its maintenance or transfer. A number of studies (e.g., Shea & Morgan, 1979; Wright, Black, Immink, Brueckner, & Magnuson, 2004; Wulf & Schmidt, 1989) have shown that facilitatory effects noted during treatment sessions are not necessarily predictive of post-treatment retention of skills (i.e., learning). Rather, a number of variables interact to affect motor learning in a complex fashion. These variables include (1) type of feedback, (2) the amount of repetitive practice, (3) the schedule under which the practice trials are performed, and (4) the supporting cognitive mechanisms for learning shown by the participant, including attention, memory, and motivation.

The primary goal of the current study was to determine whether EMA-derived visual feedback improved speech production accuracy in an adult with acquired AOS and concomitant aphasia. It was hypothesised that SMTs treated with EMA would demonstrate robust acquisition, maintenance, and generalisation (i.e., improved performance with untrained items) in comparison with unrelated control SMTs.

A secondary question addressed the schedule under which EMA feedback information was provided. Studies of limb motor movement have suggested that reducing the frequency of feedback presentation (e.g., from 100% to 50%) may decrease the rate of acquisition but enhance retention and generalisation to similar (untreated) behaviours (Bruechert, Lai, & Shea, 2003; Wulf, Schmidt, & Deubel, 1993). Similar patterns have been noted in recent studies of speech production, including articulation (Adams & Page, 2000; Austermann et al., 2008; Clark & Robin, 1998) and voice (Steinhauer & Grayhack, 2000).

Austermann and colleagues (2008) examined frequency feedback effects in the speech treatment of four individuals with AOS. Treatment involved producing nonword syllables or syllable sequences. Transfer was tested to untreated stimuli of similar complexity and to more complex real words related to the treated behaviours. Feedback was given on 60% of productions in the low-frequency feedback condition, and on 100% of the productions in the high-frequency feedback condition. It was found that one participant showed enhanced performance during acquisition under the high-frequency feedback condition and two participants showed enhanced maintenance and transfer during the low-frequency feedback condition. These findings were interpreted as qualified support for reduction of feedback in the structured intervention of AOS.

Feedback frequency research has mostly focused on a type of feedback known as *knowledge of results* (KR), which describes the outcome of a motor act. However, it has generally been assumed that the principles discovered for KR would be applicable when feedback is about movement quality, known as *knowledge of performance* (KP) (Schmidt & Lee, 1999, p. 325; Weeks & Kordus, 1998). In the current research a combined form of KR and KP visual feedback is provided to treat tongue-tip positioning after stroke, with feedback frequency manipulated to investigate this particular prediction of schema theory. We further predict that low-frequency feedback would result in reduced acquisition but enhanced generalisation and maintenance of treated behaviours (in comparison to high-frequency feedback).

METHOD

Participant

The participant was a 50-year-old female monolingual speaker of American English who sustained a left-hemisphere middle cerebral artery CVA 9 months before treatment. She is a homemaker with 12 years of education. Prior to enrolling in this study she had received individual and group therapy for approximately 7 months on an outpatient basis. Table 1 shows initial cognitive, linguistic, and speech assessment data. The participant was diagnosed with a moderate Broca's aphasia, based on clinical examination and results of the Short Form Boston Diagnostic Aphasia Exam BDAE-3; (Goodglass, Kaplan, & Barresi, 2001).

An oral mechanism examination revealed no oral apraxia. Participant behaviours were consistent with the unique pattern of speech characteristics of AOS as defined by McNeil et al. (1997), including overall slow rate, extended segment (consonants and vowels) and inter-segmental durations (with occasional schwa insertion), phoneme distortions, and prosodic impairment. For instance, when attempting the word "flashlight" she produced [flæ#tʃəlaɪt].

Experimental stimuli

Treated SMTs, (/j/, /θ/, and /tʃ/) in varying CVC contexts, and two untreated controls (/br/ and /sw/) were selected based on frequency and consistency of errors produced on a 200-item list of phonetically balanced single words. For the treated SMTs, the majority of errors were incorrect place of articulation. The control SMTs also included some schwa-intrusion errors. Treated groups of SMTs were assigned (in counterbalanced fashion) to frequent and infrequent feedback conditions, with /j/ and /tʃ/ SMTs receiving 100% feedback and /θ/ SMTs receiving 50% feedback. As part of a larger study investigating SMTs in different syllable positions, and based on this participant's unique error pattern, the SMTs containing /j/ and /tʃ/ for this participant were assigned to initial position, and those containing /θ/ were assigned to the medial position.

TABLE 1
Participant speech, language, and cognitive characteristics

Assessment measure	*Score*
Boston Diagnostic Aphasia Exam (BDAE) Articulatory agility (Goodglass et al., 2001)	3/7
BDAE Phrase length	4/7
BDAE Grammatical form	3/7
BDAE Melodic line	2/7
BDAE Word finding relative to fluency	5/7
BDAE Auditory comprehension	30%
Story Retell Procedure (SRP)(McNeil et al., 2007)	Mean % IU: 12 *
Immediate and Delayed Story Retell Subtests (Arizona Battery for Communication Disorders of Dementia) (Bayles & Tomoeda, 1993)	Ratio: 100 **
Assessment of Intelligibility of Dysarthric Speech (Single Words) (Yorkston & Beukelman, 1984)	Intelligibility: 46%
Word intelligibility task(Kent, Weismer, Kent, & Rosenbek, 1989)	Intelligibility: 38%

*Percentage of available information units produced by the participant.

**Ratio of the delayed retell compared to the initial retell (the delayed recall/immediate recall × 100) on the *Story Retelling Test* of the *Arizona Battery for Communication Disorders of Dementia.*

Five repetitions of a probe list containing five words for each treated SMT group, between three to eight words[1] for the untreated SMTs (to determine response generalisation), and between 17 to 26 control SMTs (assigned by a Latin square method) were audio-recorded at the beginning of each session. To avoid potential confounds of EMA sensor interference, experimental probe items were elicited without EMA sensors. The words in the experimental probe lists contained a variety of vowels and consonants (but were not closely matched on phonetic structure). All treated and untreated stimuli were probed before each treatment session and thus reflect any maintenance of performance accuracy resulting from the previous treatment session(s).

Experimental design

The design was multiple baseline across behaviours with frequent and infrequent feedback conditions. The participant's baseline performance was measured during the first four sessions. Treatment was then applied sequentially to the five words representing the selected SMT (one SMT at a time) until the average of treated targets for three consecutive probes reached 80% correct or higher, or a total of 20 training sessions had elapsed. Long-term maintenance was determined in two sessions conducted one month post-treatment.

An important difference between the current intervention and more conventional approaches is that it is assumed each target item is potentially a distinct SMT, for which the participant is separately baselined and trained with a unique constellation of visual kinematic feedback patterns. Thus mastery of one /j/-containing word is not automatically assumed to be linked to other phonetic combinations containing /j/. For instance, the visuo-motor feedback patterns for the phonetic combination /jut/ of *Utah* are quite different from those of /jɔɹ/ in *yourself.*

Treatment sessions and procedure

The participant was instructed that she would receive visual feedback information regarding the position and movement of her tongue during speech, and that she should attempt to "hit the targets" with her tongue during treatment. Aside from a customary 5-minute warm-up period (to allow patients to accommodate to having an EMA sensor in the mouth), no other instructions or practice trials were given. During baseline testing, productions were elicited from a spoken and written stimulus provided by the investigator. Treatment was then applied sequentially to the /j/-containing word targets, followed by the /θ/-containing word targets, then the /tʃ/-containing word targets. During the /j/ sessions, one word was practised until 40 correct responses were elicited, then the next /j/-containing target word was practised, and so on, for a minimum of 200 accurate trials per session (5 targets × 40 responses). After reaching criteria over several sessions, the participant was switched to /θ/-containing words, then /tʃ/-containing words. Thus the words within each session were in blocked order, with order randomised over sessions. Treatment sessions lasted approximately 45 min and were held three times a week. Blocked stimulus presentation was used in

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[1] A completely balanced design would have included five treated and untreated SMTs. However, it was difficult to obtain sufficient /θ/-containing words that had not already been used in the assessment. To provide a roughly similar number of treated and untreated items, extra SMTs were added to the /j/ and /tʃ/ groups.

each session both for practical reasons (difficulty resetting spatial targets for different groups of SMTs in real time) and to compare results with previous studies that have presented data in blocked fashion (Katz et al., 1999, 2002).

During treatment, EMA feedback was delivered with a Carstens AG100 Articulograph equipped with real-time feedback display software. The participant was seated in a sound-treated room wearing the articulograph helmet with one sensor attached 1 cm posterior to the tongue tip (for the /θ/ and /tʃ/ SMTs), or one attached to the tongue dorsum for the /j/ SMTs. She faced a monitor displaying an image of her current tongue position. Using a mouse drawing tool, investigators designated a "target zone" of fixed dimensions, corresponding to the participant's accurate placement of the tongue tip for the selected SMT. This information was used by the participant to guide her tongue towards the correct place of articulation. Target words were repeated following a spoken and written example provided by the investigator. During treatment the investigator was positioned out of view so that no visual cues were available during the spoken model. Spatially accurate movement patterns (i.e., reaching the target) were followed by a tone, and a rising balloon image moved on the display. Feedback was given one trace at a time, with the screen cleared after each attempt. In the 50% feedback condition (for the /θ/ SMTs) the video monitor was programmed to randomly blank out for half the trials. During this time, the participant could not view her tongue tip position. Additional details on the EMA feedback procedure are given in Katz et al. (1999).

Scoring procedure and reliability

Productions from each audio-recorded probe list were played to a trained examiner (DG). A production was scored as "correct" if both the targeted consonant and subsequent vowel were judged to be produced accurately and intelligibly. An analysis of inter-rater reliability using a second judge on 5% of the data indicated 88% agreement.

RESULTS

Because of considerable individual SMT variability, and because canonical phonemes are not assumed to represent a response class, the typical method of displaying results as a staggered graph of pooled phoneme acquisition (e.g., /j/, followed by the next phoneme, and so forth) was not used. Instead, the data are displayed separately by individual SMT (Figures 1 to 4). In all cases, treatment outcome was first determined by visual inspection, then by consideration of Cohen's *d* effect sizes for true baseline vs treatment, baseline vs post-treatment, and baseline vs long-term maintenance comparisons (Beeson & Robey, 2006). Effect sizes were calculated based on all data points in each experimental phase, and not on a certain number of points within each phase. Visual inspection was conducted by two expert judges who were unfamiliar with this participant. Judgements of generalisation (i.e., determining if treatment influenced untreated behaviours during a given treatment phase) were made by these same judges, with 94% inter-rater reliability. Visual inspection judgements were based on changes in trial-to-trial variability, and the magnitude and slope of change from the baseline and across preceding phases.

For the first group of SMTs (initial /j/), acquisition was judged to occur for 4/5 trained words, with *d* values ranging from 1.1 to 7.74 (x = 4.24). These SMTs were maintained post-treatment ($d = 1.47$ to 7.83; x = 4.61) and at the 1-month long-term probe ($d = 1.41$ to 6.09; x = 3.64). Improved performance and short-term maintenance were

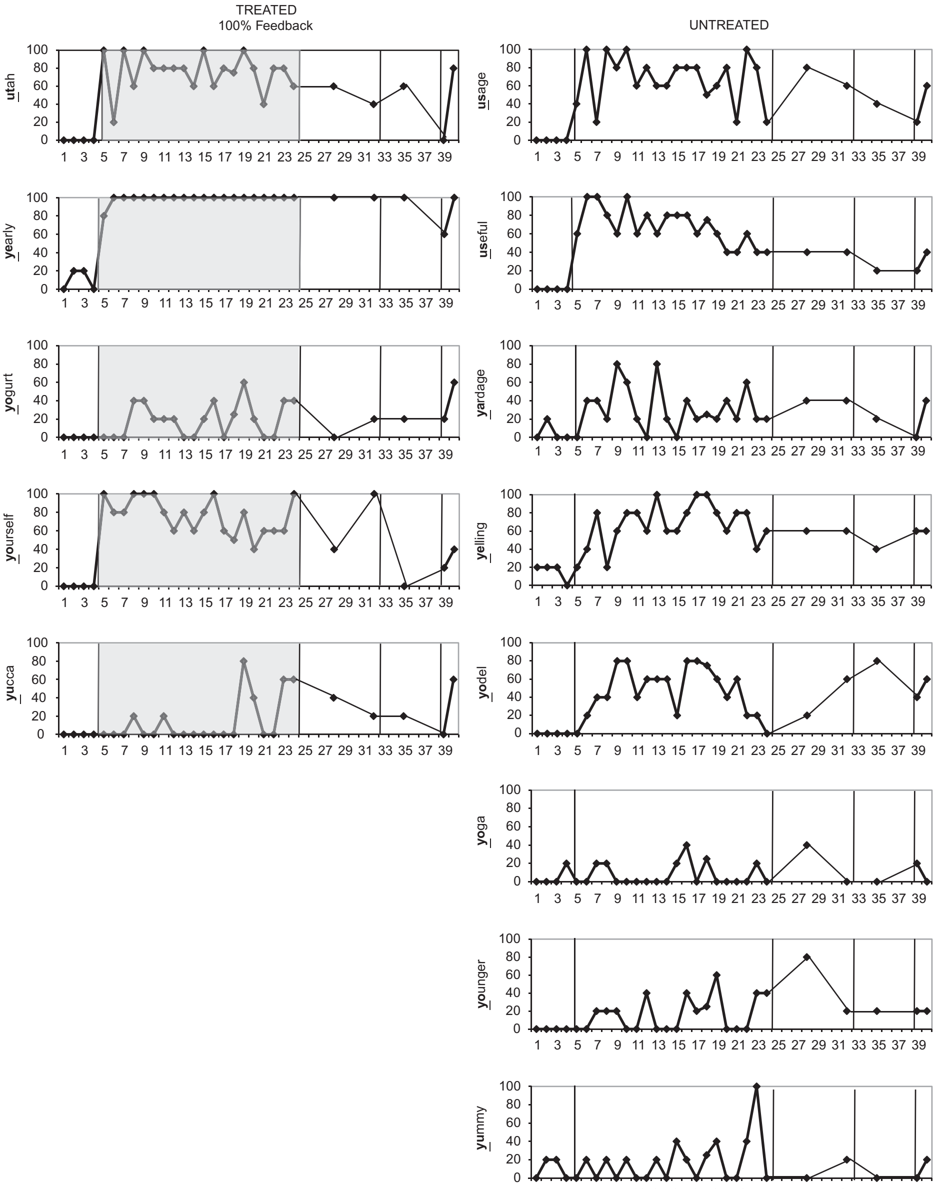

Figure 1. Baseline, acquisition, maintenance, and follow-up data for /j/, the first treated group of SMTs. For the treated words (left column) the treatment sessions are shaded. The untreated words (right column) probed response generalisation. Accuracy is percent correct out of five repetitions per session per word. A check indicates positive outcome for acquisition, maintenance, or long-term maintenance.

also judged for five of the eight untreated stimuli included as "near" target probes for response generalisation (*usage*, *useful*, *yardage*, *yelling*, *yodel*), with *d* values ranging from 1.89 to 5.20 (generalisation; x = 3.22), and 2.75 to 4.74 (post-treatment maintenance; x = 3.75). With one exception, production was also maintained in these words at 1 month post-treatment. There was little evidence of generalisation during /j/-containing probe items from the treatment of the subsequent /θ/- and /tʃ/-containing SMTs.

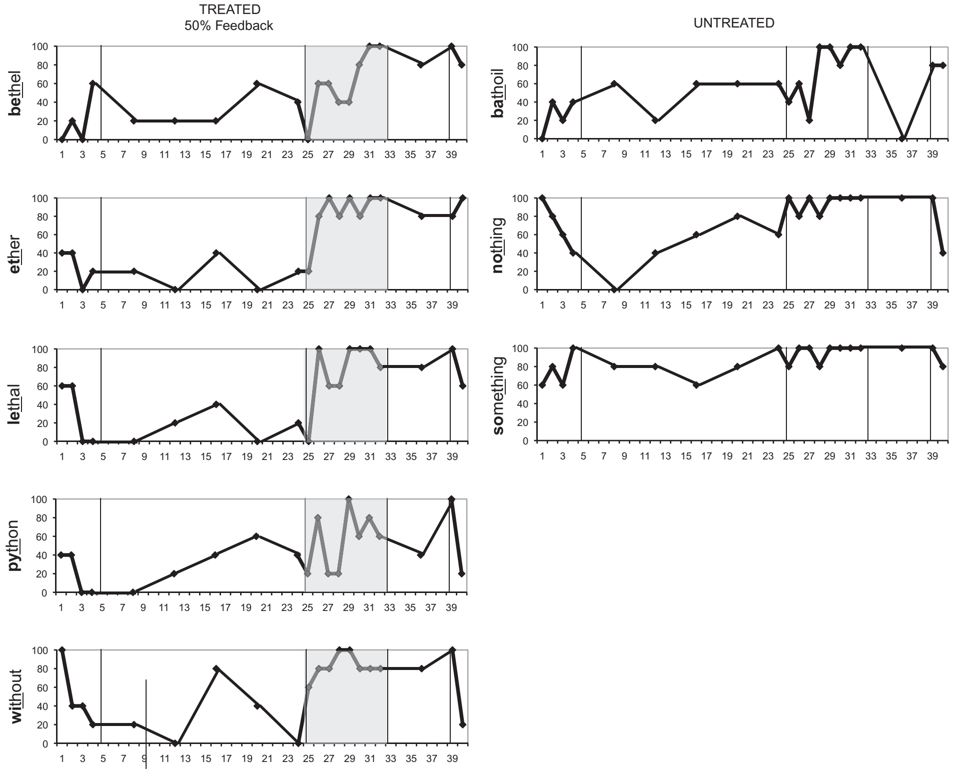

Figure 2. Baseline, acquisition, maintenance, and follow-up data for /θ/, the second treated group of SMTs. For the treated words (left column) the treatment sessions are shaded. The untreated words (right column) probed response generalisation. Accuracy is percent correct out of five repetitions per session per word. A check indicates positive outcome for acquisition, maintenance, or long-term maintenance.

The next treated SMT, medial /θ/, was produced with higher baseline accuracy than the /j/ SMTs, and with considerably more variability. All five treated items were judged as showing acquisition (d = 1.26 to 3.61; x = 1.95). Two of these five SMTs (*bethel* and *without*) were maintained at 1 month post-treatment (d = 2.83 to 4.05). All three untreated probes showed improved performance (d = 1.26 to 3.61; x = 1.31), with two of these showing maintenance at 1 month post-treatment (d = 0.78 and 4.05).

The third treated group of SMTs, initial /tʃ/, was judged as showing improved performance for all of the five treated SMTs. However, these gains could only be specifically attributed to /tʃ/ treatment for three of the five targets (d = 2.05 to 3.06), because of generalisation from prior treated /j/- and /tʃ/-containing targets. Two of the treated items appeared well maintained (relative to baseline) at 1 month post-treatment (d = 2.09 to 2.57). Improved performance and maintenance (d = 0.81 to 2.31; x = 1.26) were also judged for all six untreated targets. However, generalisation from previously treated targets was clearly involved in the improvement of these items.

The majority of the untreated (control) words showed increased variability during the training phases for the three treated targets. However, there was little improvement by 1 month post-treatment, and there were many instances of no change during the course of the experiment. In summary, there were sufficient stable baselines to suggest that the gains noted for treated items did not result from across-the-board improvement

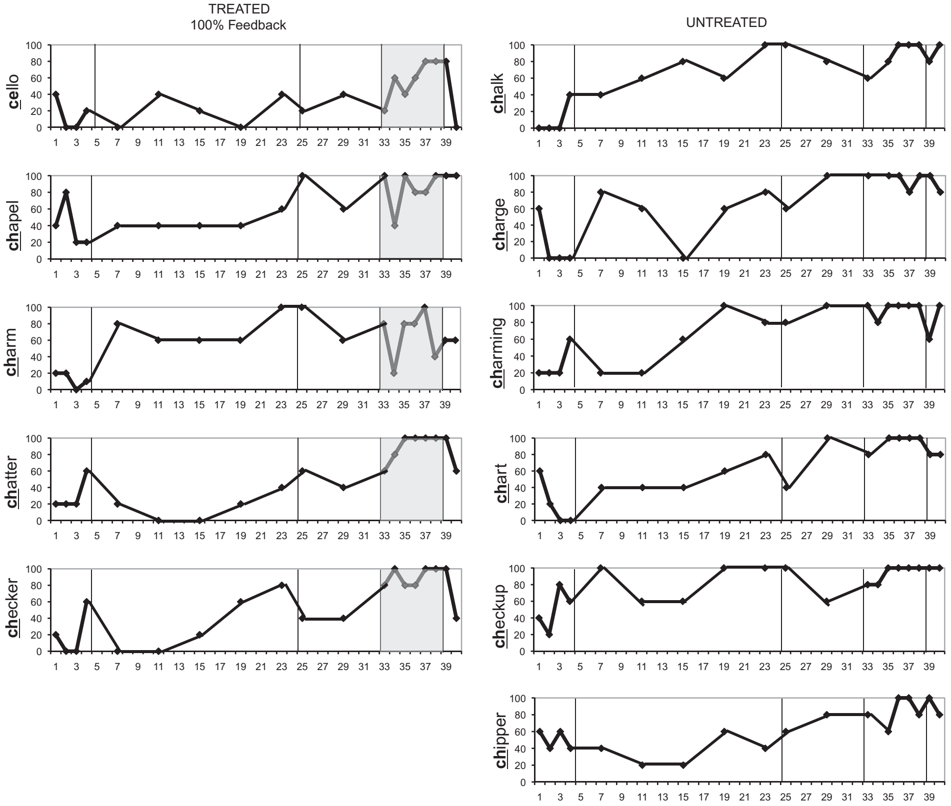

Figure 3. Baseline, acquisition, maintenance, and follow-up data for /tʃ/, the third treated group of SMTs. For the treated words (left column) the treatment sessions are shaded. The untreated words (right column) probed response generalisation. Accuracy is percent correct out of five repetitions per session per word. A check indicates positive outcome for acquisition, maintenance, or long-term maintenance.

or unassisted recovery. Contrary to predictions, treatment of /θ/-containing SMTs with 50% feedback corresponded with relatively rapid acquisition and poor overall maintenance, compared to the targets treated with 100% feedback.

DISCUSSION

The main finding of this study is that augmented kinematic feedback improved production for a majority of treated targets for an individual with AOS. For the first treated SMT, organised around the /j/ gesture, most of the targets probed showed acquisition, post-treatment maintenance, and long-term maintenance. Adequate controls (i.e., unrelated probe items obtained over the course of treatment) suggested that the cases of the /j/ SMT acquisition could be attributed to the treatment. Similar patterns were noted for the next treated group of SMTs, /θ/, with most items acquired and maintained, both immediately post-treatment and at 1 month post-treatment. The third treated group of SMTs, /tʃ/, presented a greater challenge for interpretation: Improved performance and maintenance were noted for all treated and some untreated SMTs, although generalisation from previously treated targets (i.e., /j/ and /θ/ groups of SMTs) occurred for some items.

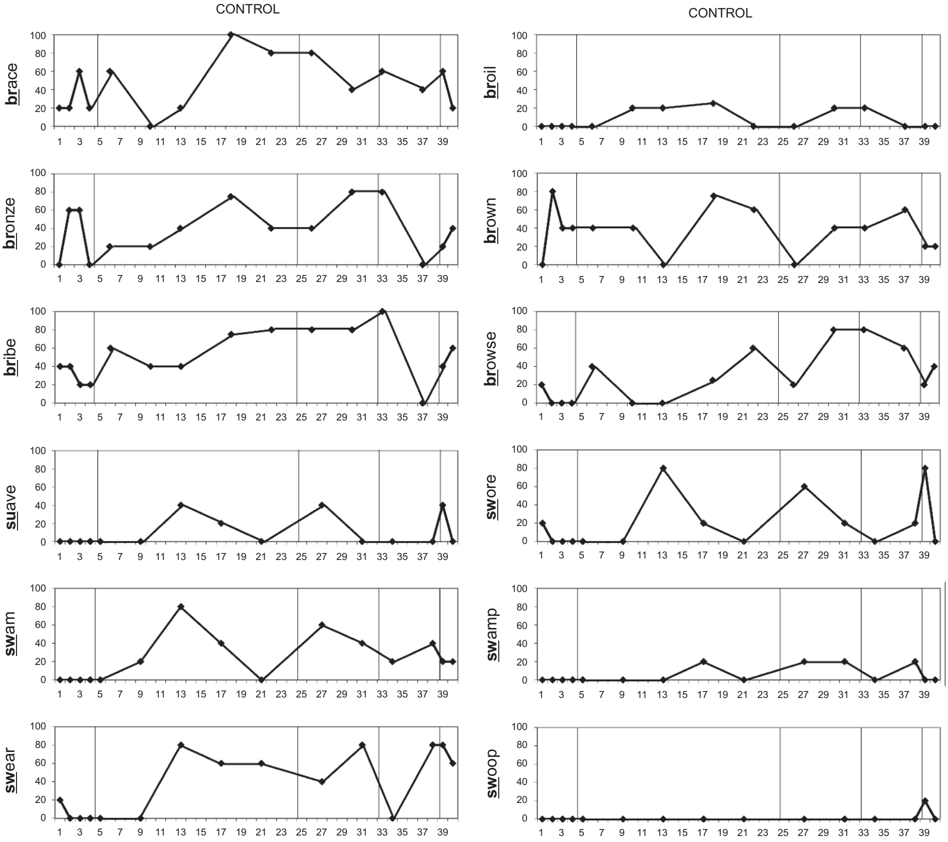

Figure 4. Accuracy for producing the untrained (control) sounds /br/ and /sw/ during the baseline, acquisition, maintenance, and follow-up phases of the experiment. Accuracy is percent correct out of five repetitions per session per word. A check indicates positive outcome for acquisition, maintenance, or long-term maintenance.

Considered in the framework of schema theory, the general outcome of the intervention may be attributed to strengthening of the GMP, parameters, or both. At a more detailed level, the patterns of SMT generalisation observed are puzzling: Within a given set of SMTs there was item-specific variability among the treated (e.g., *Utah* vs *yucca*) and untreated (e.g., *usage* vs *yummy*) items. At a minimum, this suggests that EMA feedback treatment does not operate uniformly at the level of a canonical phoneme. However, these differences do not seem to be attributable to phonetic context effects at the level of the syllable, since there were also cases in which a treated item generalised to an untreated item sharing the same CV context (e.g., *yogurt*, *yodel*), but did not generalise to other untreated items in the same SMT category (e.g., *yoga*). In addition, there were untreated CV combinations acquired (e.g., *yardage*, *yelling*) that were not treated. There are a number of possible explanations for these patterns, including lexical-level issues or motoric/planning demands for segments larger than the CV syllable. Although the details are not yet clear, an explanation in terms of underlying motoric complexity is suspected to provide the best understanding of these and related data.

A secondary finding is that treatment of /θ/ SMTs with 50% feedback corresponded with relatively rapid acquisition and a low degree of overall maintenance, compared to the targets treated with 100% feedback. This finding does not agree with some of the patterns noted in studies of limb (e.g., Bruechert et al., 2003) and speech (e.g., Austermann et al., 2008; Clark & Robin, 1998) motor learning. However, the present data must be considered with caution, as a small number of stimuli were involved and the stimuli were not balanced across frequency conditions.

The effect sizes for Cohen's *d* ranged from 0.86 to 7.74, with averages for the /j/ SMTs falling in the high 3 to 4 range, the /θ/ SMTs averaging approximately 1.5, and the /tʃ/ SMTs averaging in the 1.5 to 3 range. Although there are no motor-based treatment data from which to derive comparable benchmarks, Robey, Schultz, Crawford, and Sinner (1999) reported values drawn from a number of interventions for various language functions and used in the interpretation of data in several recent studies (2.6, 3.9, and 5.8, corresponding to small-, medium-, and large-sized effects). If these comparisons were relevant, the current findings would represent relatively small effect sizes. However, this would not be particularly surprising as the current data represent a limited, experimental intervention rather than a full-fledged therapy programme. While the eventual goal is to incorporate this type of technology into a hierarchical therapy model, the current participant received only brief motor practice guided by the machine display.

One last point deserves mention: Whereas the participant received visual feedback for consonant place of articulation, her productions were scored using more stringent criteria, i.e., perceptually correct production of CV portions of the word (across place, manner, and voicing). Thus the current data likely underestimate actual training effects because the place of articulation for target SMTs probably improved at a better rate than whole-syllable performance.

In summary, the findings of this study provide qualified evidence that kinematic feedback improved the speech of this individual with AOS. Systematic replication of this technique on additional individuals with varying factors known to affect motor and verbal learning will determine the conditions under which this technique is efficacious and effective.

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