FEEDBACK CONTROL IN TREATMENT FOR APRAXIA OF SPEECH

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by
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Abstract

Apraxia of speech (AOS) is a motor speech disorder associated with an impairment in motor planning and programming. It is therefore a logical step to derive treatment of the disorder from the principles of motor learning. Principles of motor learning refer to relatively predictable benefits of certain practice conditions over others (e.g., random practice enhances learning compared to blocked practice). A number of studies have begun to examine principles of motor learning in treatment for AOS (e.g., Austermann Hula et al., 2008; Katz et al., 2010). The current project aims to continue the investigation of motor learning principles and its application to motor speech disorders. In particular, the primary goal of this study is to examine the role of feedback control in treatment for AOS. Two types of feedback control are typically distinguished: self-controlled feedback and clinician-controlled feedback (Chiviacowsky & Wulf, 2004; Chiviacowsky & Wulf, 2007; Janelle, Barba, Frehlich, Tennant, & Cauraugh, 1997; Wulf, 2007). A secondary goal is then to examine the efficacy of script training for AOS. Youmans et al. (2011) provided promising initial evidence supporting its efficacy for AOS, yet no studies have replicated these findings (Ballard et al., 2015).

The results of this study suggest that self-controlled feedback is more efficacious in treating adults with AOS than clinician-controlled feedback. Greater improvements of performance for self-controlled feedback were noted especially in accuracy of productions. There was the potential to impact rate of speech as well. Findings across conditions (treated versus untreated scripts) also indicate that script training is an efficacious method of treating adults with AOS.

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I greatly thank the participant of this study as well. His dedication and enthusiasm were driving forces of this study, and the early morning sessions were highlights of my graduate career. His involvement made the study possible, and I am truly grateful.

Finally, my deepest appreciation is extended to my family and friends. To my siblings, I am thankful for your continuously uplifting spirits. And to my mother, my greatest supporter, I could not have done this without you, and I dedicate this paper to you.

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CHAPTER 1

INTRODUCTION

Background

Apraxia of speech (AOS) is a neurological motor speech disorder (MSD), most often caused by stroke. AOS is considered an impairment in the ability to plan the motor commands necessary for proper movements in speech production (Duffy, 2012). The severity of AOS ranges from minimal (e.g., minor sound distortions) to a complete inability to produce speech (Ballard et al., 2015; Mauszycki & Wambaugh, 2011). Its defining clinical characteristics are slow and segmented speech, errors in articulation (in particular speech sound distortions), and abnormal prosody (Ballard et al., 2015).

Prevalence of AOS is unknown, but estimates from combined sources (Duffy, 2012; NIDCD, 2008; National Aphasia Association, n.d.) suggest that approximately 320,000 people have a primary diagnosis of AOS in the United States, with an incidence of almost 29,000 new cases each year. Current treatment for AOS consists of four general categories: articulatory/kinematic, prosody (rate/rhythm control), alternative and augmented communication (AAC), and intersystemic facilitation/reorganization (Ballard et al., 2015; Mauszycki & Wambaugh, 2011). The majority of treatment falls under articulatory/kinematic, which is motivated by the disorder's impairment in motor planning and programming (Ballard et al., 2015; Rosenbek, Lemme, Ahern, Harris, & Wertz, 1973). This particular approach focuses on improving spatial and temporal aspects of speech production in order to encourage speech sound accuracy (Mauszycki & Wambaugh, 2011;

Ballard et al., 2015). Articulatory/kinematic treatment consists of repeated motoric practice, modeling-repetition, and articulatory cueing (Mauszycki & Wambaugh, 2011). It has been found to be effective in treating even severe AOS cases (Wambaugh, Duffy, McNeil, Robin, & Rogers, 2006). Current treatments for AOS have significantly improved in efficacy over the decades, but there is still a need for replication of treatment research as well as testing variations of treatment protocol in order to maximize the potential benefits of treatment with limited resources (Ballard et al., 2015; Wambaugh et al., 2006). According to Ballard et al. (2015), the median number of treatment sessions in the literature is 30, and in most studies, improvements do not result in complete elimination of speech difficulties. In many clinical settings, 30 sessions devoted entirely to AOS is not realistic. Therefore, it is important to try and find ways to maximize the effects and efficiency of the limited available treatment time. One promising approach to identifying optimal treatment factors for AOS is to examine the role of principles of motor learning, which refer to the relatively robust benefits for motor learning of some conditions compared to others. The present study addresses one particular principle of motor learning, namely feedback control, which compares self-controlled feedback to clinician-controlled feedback.

Principles of Motor Learning

Principles of motor learning (PML) have the potential to optimize motor recovery and the effective learning of motor skills (Levin, Weiss, & Keshner, 2014; Schmidt & Bjork, 1992; Poole, 1991). Essentially, they are elements addressed in practice that enhance learning and retention of novel movements (Bislick, Weir, Spencer, Kendall, & Yorkston, 2012).

These principles are defined as the relatively predictable benefits of certain practice conditions over others. Some key principles include random practice compared to block practice, and feedback frequency (e.g., greater learning with sparse feedback compared to frequent feedback) (Schmidt & Bjork, 1992; Levin, Weiss, & Keshner, 2014; Hemayattalab, Arabameria, Pourazar, Ardakani, & Kashefi, 2013; Poole, 1991). The motor learning literature has substantiated the benefits of PML in healthy participants (e.g., Hansen, Pfeiffer, & Patterson, 2011; Kaefer, Chiviacowsky, Meira Jr., & Tani, 2014; Lessa & Chiviacowsky, 2015; Wulf, Höß, & Prinz, 1998; Wulf, Shea, & Lewthwaite, 2010) as well as in limb motor rehabilitation (Burtner, Leinwand, Sullivan, Goh, & Kantak, 2014; Landers, Wulf, Wallmann, & Guadagnoli, 2005; Levin et al., 2014; Muratori, Lamberg, Quinn, & Duff, 2013).

PML have been applied to research involving more than just typically developing individuals as well. Current research integrates PML into treatment for individuals with motor disorders and injuries, including cerebral palsy, traumatic brain injury (TBI) resulting in neurorehabilitation, and Parkinson's disease, among others (Chiviacowsky, Wulf, Lewthwaite, & Campos, 2012; Chiviacowsky, Wulf, Machado, & Rydberg, 2012; Huang & Krakauer, 2009; Krakauer, 2006; Cano-de-la-Cuerda et al., 2015). In these cases, it is assumed that the improvement of motor skills when applying the principles to practice for healthy individuals will extend to improvement of motor skills for those with motor disorders. Winstein (1991) draws on the PML and argues that motor learning research is meaningful for physical therapy, as motor skills literature can aid in the movement sciences. This is also true for occupational therapy – Poole (1991) remarks that occupational therapists that are involved in the training and retraining motor skills in their patients can benefit from knowledge of instructional methods found in the PML from motor literature. Additionally, Chiviacowsky, Wulf, Machado, and Rydberg (2012) analyzed PML in individuals with Down syndrome and found greater learning given particular conditions over others. Overall, it is evident that the principles of motor learning are effective in acquiring and retaining motor skills in healthy individuals as well as being beneficial in rehabilitation and skill learning of individuals with disabilities.

Feedback Control

Among the PML, feedback variations have been the subject of many studies. A plethora of research has determined the efficacy of feedback in motor learning literature for participants including older adults, individuals with Down syndrome, individuals with Parkinson's disease, introverts and extroverts, and individuals with cerebral palsy (Lessa & Chiviacowsky, 2015; Chiviacowsky, Wulf, Machado, & Rydberg, 2012; Chiviacowsky, Wulf, Lewthwaite, & Campos, 2012; Kaefer et al., 2014; Hemayattalab, 2014; Hemayattalab et al., 2013). Based on the results from these studies that support particular feedback conditions over others (e.g., self-controlled feedback is more efficacious in learning and retaining novel motor movements), questions about feedback and its effects on motor speech skills are justified.

Feedback control, which is the focus of this study, is a particularly robust principle that refers to which party determines whether feedback is provided following a trial, the clinician or the client. Two types of feedback control are typically distinguished: self-controlled feedback and clinician-controlled feedback (Chiviacowsky & Wulf, 2004; Chiviacowsky & Wulf, 2007; Janelle, Barba, Frehlich, Tennant, & Cauraugh, 1997; Wulf, 2007). In speech treatment, it is more common than not for the clinician to decide on which trials to give feedback to the client. Clinician-controlled feedback is considered to be the gold standard in clinical practice, as clinician input is grounded in experience and expertise in the field. This feedback is typically used during clinical practice because of the extensive knowledge clinicians possess in identifying inaccuracies of productions (e.g., distortions, dysprosody). Because of this, there has been a tendency to focus on the feedback-giver over the feedback-processor in a clinical setting. In other words, the feedback-giver (i.e., the clinician) has greater control over feedback than the individual receiving feedback. The motor learning literature, however, reveals an abundance of research to support the opposite, namely that feedback controlled by the client (i.e., the client decides when he would like feedback from the clinician following a trial) is more efficacious than feedback controlled by the clinician (Chiviacowsky & Wulf, 2004; Janelle et al., 1997; Wulf, 2007). In motor literature, it has been determined that self-controlled feedback is more effective than externally imposed feedback in ball throwing, sequential timing tasks with the index finger, and in motor perception tasks (Sigrist, Rauter, Riener, & Wolf, 2013). Also, attention to self-regulation has resulted in increased learning and performance by the participant according to Janelle et al. (1997). Chiviacowsky and Wulf (2004) found in their motor learning study that self-controlled feedback was more effective when the learner could make the decision about receiving feedback after a trial, rather than making the decision about feedback before the trial. Janelle et al.'s study (1997) came to the conclusion that when participants were in control of when they received feedback, they had the tendency to request feedback less during treatment. They also retained learned skills equal to, if not better than, participants who did not have control of feedback (Janelle et al., 1997).

Feedback Principles in Speech Motor Learning

Though research about the efficacy of the PML in treating MSDs has only just begun in the field, its emerging literature supports the application of feedback variations in speech motor learning. Adams and Page (2000) analyzed the effects of feedback frequency, among other motor learning principles, on speech of participants with no noted speech impairments. The study concluded that sparse feedback – feedback after every five trials – resulted in better retention than feedback on every trial (Adams & Page, 2000). Kim, LaPointe, and Stierwalt (2012) found similar results about feedback frequency for novel speech learners. Van Stan et al. (2017) assessed effects of summary feedback (i.e., cumulative feedback following a succession of trials) in individuals with vocal nodules and found that less frequent feedback was associated with greater generalization of speech tasks than feedback following every trial. When it comes to the application of these motor learning principles to AOS, there have been several relevant studies as well. Austermann Hula, Robin, Maas, Ballard, and Schmidt (2008) as well as McNeil et al. (2010) looked at feedback frequency as a condition in treatment for acquired AOS. Austermann Hula et al. (2008) found that reducing feedback enhanced retention and transfer of speech skills, and the results of McNeil et al. (2010)'s study were uninterpretable due to limited patterns of randomization in the study. Maas, Butalla, and Farinella (2012) studied the effects of feedback frequency on children with childhood apraxia of speech and found mixed results – some children responded better to less frequent feedback while others responded better to a higher frequency of feedback. Thus, feedback frequency effects have been observed in some but not all individuals with AOS. Given the relatively consistent benefits of self-controlled feedback in other motor learning tasks, it is possible that feedback control will have more consistent effects in speech motor learning in AOS as well. However, as of yet, no published studies have examined feedback control in AOS treatment, or in speech motor learning in general.

Purpose of the Present Study

The primary goal of this study is to examine the role of feedback control in treatment for acquired apraxia of speech. In particular, this study will compare self-controlled feedback and clinician-controlled feedback in treatment of an individual with AOS using a single-case experimental design. If speech motor learning in AOS follows similar principles as those observed in the motor learning literature, then we expect greater improvement with self-controlled feedback than with clinician-controlled feedback (Hypothesis 1). Alternatively, if it is possible that typical clinical practice (involving clinician-controlled feedback) based on clinical expertise is optimal, then clinician-controlled feedback may lead to greater improvement than self-controlled feedback (Hypothesis 2).

A secondary goal of this study is to examine the efficacy of script training for AOS treatment. Feedback control will be compared in the context of script training for AOS, and therefore this study will also provide one of the first replications of the approach as applied to AOS (Youmans, Youmans, & Hancock, 2011). Script training has been replicated previously with an individual with a primary diagnosis of AOS by Mahoney (2019), with results supporting the efficacy of the treatment method for acquired AOS. Script training involves practicing and automating functional phrases in a script developed together with the client and clinician. The treatment serves the purpose of supplying the speaker with a few practiced, automatized phrases to fit conversational topics that are personal and common to the speaker (Youmans et al., 2011). As such, self-control already forms an integral component of this approach, which ties it into this study's focus on self-regulation. Results of Youmans et al.'s study (2011) concluded that script training for AOS was successful, functional, and practical for participants. Youmans et al. (2011) provided promising initial evidence in supporting the treatment's efficacy for AOS, and one additional study has replicated these findings (Mahoney, 2019).

CHAPTER 2

METHODS

Participant

Being a single-subject experimental design, one adult participant was selected with acquired AOS, recruited from Temple University's Speech-Language-Hearing Center (TUSLHC). The participant "Robert" was a 55-year-old right-handed White non-Hispanic man. He was a monolingual speaker of American English with 10 years of formal education and worked as a concierge at a hotel prior to his stroke. Robert suffered a stroke in his left hemisphere 8 years prior to the start of this study. The stroke resulted in aphasia and AOS and right-sided weakness in upper and lower extremities. He reported no prior history of speech, language, or hearing disorders, nor a history of neurological conditions or learning disabilities. No lesion information was available. This research was conducted according to procedures approved by the Temple University IRB (protocol #23430). Robert gave informed consent for voluntary participation and received compensation for transportation costs at a rate of $6 per session.

At the time of the study, Robert was diagnosed with AOS of mild-moderate severity by a clinical researcher with 20 years of experience with AOS based on presence of current consensus features, including slow and effortful speech, speech sound distortions and distorted substitutions, segmented speech, and dysprosody (e.g., McNeil et al., 2009; Wambaugh et al., 2006). In addition, he exhibited articulatory groping, inconsistent presence of errors, and increasing errors with increasingly complex words. These features were present across speech tasks; clinical judgment was based on speech samples from a variety of speech tasks, including those from the *Apraxia Battery for Adults – 2nd Edition* (ABA-2; Dabul, 2000; See Table 1). This judgment of mild-moderate AOS was confirmed by the score on the Apraxia of Speech Rating Scale (v.3; Strand et al., 2014; Utianski et al., 2018; See Table 1), a structured scale to rate presence and severity of speech characteristics associated with AOS. The ASRS has been validated against clinical judgment (Strand et al., 2014) and has been shown to have good inter-rater reliability (e.g., Basilakos, Yourganov, Den Ouden, Fogerty, Rorden, Feenaughty, & Fridriksson, 2017; Haley, Smith, & Wambaugh, 2019; Wambaugh, Bailey, Mauszycki, & Bunker, 2019). Robert received an AOS rating of 21. According to Strand et al. (2014), a score >8 indicates presence of AOS, based on a sample of individuals with progressive AOS; recent studies applying the ASRS to stroke-based AOS have also adopted AOS ratings >8 as indicative of AOS (e.g., Basilakos et al., 2017; Haley et al., 2019; Mailend, Maas, Beeson, Story, & Forster, 2019; Wambaugh et al., 2019). There was no evidence for either nonverbal oral apraxia or limb apraxia.

Aphasia was diagnosed based on clinical judgment and the *Western Aphasia Battery – Revised* (WAB; Kertesz, 2006; See Table 1). At the time of the study, Robert had moderate severe aphasia, characterized by significant word finding difficulties, nonfluent speech consisting primarily of content words, and good auditory comprehension. He produced occasional semantic paraphasias. In conversational speech, Robert's speech was considered agrammatic with frequent omission of function words. Reading and writing were not formally assessed though he was able to read short phrases. According to the WAB, the Robert's aphasia was classified as borderline anomic, but according to clinical judgment, his aphasia was considered to be primarily a Broca's aphasia, on the basis of his nonfluent and agrammatic speech output during conversational speech). Screening using the Mini-Mental State Examination (Folstein, Folstein, & McHugh, 1975) indicated no evidence of cognitive impairment.

Auditory-perceptual evaluation revealed no clear evidence of dysarthria. Speech sound distortions were inconsistent and most likely due to AOS, and voice quality and resonance were normal. An oral mechanism examination revealed no abnormalities except for a mild right-sided weakness of the lips and cheek, which had no clear effects on speech (i.e., no unilateral upper motor neuron dysarthria). Robert also reported right-sided loss of taste and reduced and altered sensation (tingling) of the right side of his tongue and cheek during speech movement. The tingling sensation during speech movement was reportedly present in his right extremities as well. Robert also exhibited right-sided weakness in his arm and leg but did not require a cane for walking.

Design

This study involved a single-case experimental design, in particular an alternating treatments design, with different treatment target sets for each condition. The focus was on the feedback control type, and the efficacy of either self-controlled feedback or clinician-controlled feedback during treatment. The order of conditions in each session was counterbalanced to avoid systematic order effects. In order to control extraneous variables, there was a control set of two scripts included in this design that remained untreated. It served as a basis of comparison to evaluate the efficacy of script training. Four baseline

TEST	SUBTEST	SCORE
WAB	***Aphasia Quotient***	***73.9***
	Spontaneous Speech	***12***
	Information content	7
	Fluency	5
	Auditory Comprehension	***175***
	Yes/No questions	57
	Word recognition	58
	Sequential commands	60
	Repetition	***79***
	Naming & Word Finding	***83***
	Object naming	54
	Word fluency	11
	Sentence completion	10
	Responsive speech	8
ABA	DDK	17 (mild)
	Increasing Word Length	4 (mild)
	Increasing Word Length	10 (severe)
	Limb Apraxia	48 (none)
	Oral Apraxia	45 (none)
	Utterance Time for Polysyllabic Words	10 (none)
	Repeated Trials	16 (mild)
	Inventory of characteristics	9
ASRS		21
MMSE		27

Table 1. Participant test results.

probes were obtained of all scripts prior to the treatment phase in order to obtain baseline measures of performance.

Due to the impact of COVID-19 on university openings during the Spring and Summer semesters of 2020, the study ended prematurely. The treatment phase was intended to span over the course of two months, with 16 sessions in total (see Figure 1). Clinic closure resulted in a total of 8 completed therapy sessions spread over 5 weeks (see Figure 1). Sessions were held twice weekly for 60 minutes at a time. Two weeks of treatment had only one session per week due to participant cancellation. Once a week, the first ten minutes of a session were devoted to collection of probe data (see *Baseline and Probe Procedures* below) followed by the remaining 50 minutes of each session allotted to treatment. During sessions that did not begin with a data probe, scripts were treated for the full 60-minute session. Treatment was considered the training of scripts during which feedback was given from the clinician, controlled by either the client or the clinician (dependent on the condition in use). Following the treatment phase, an immediate post-treatment evaluation (1-week post-treatment; IP) as well as a follow-up evaluation (4 weeks post-treatment; FU) were scheduled to take place but were impacted by COVID-19 closures. No post-treatment data was collected, and results are based on data collected from weekly probes.

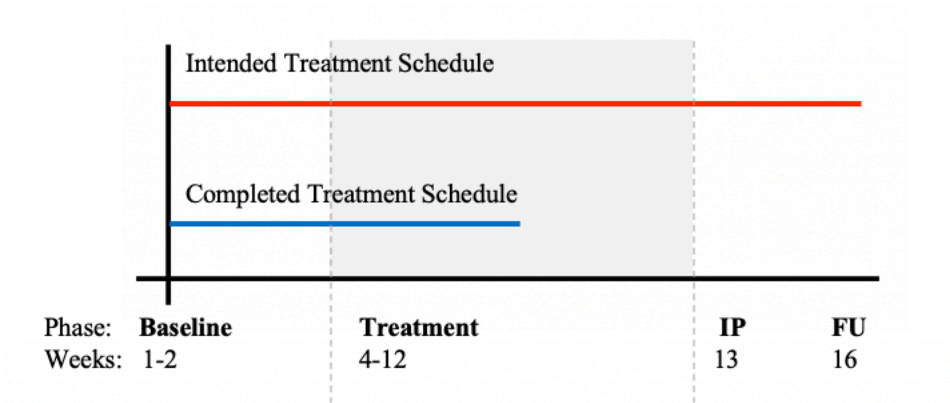

Figure 1. Intended versus Completed Treatment Schedule. Intended timeline (red) of study compared to timeline of actual completed treatment (blue).

Procedures

The study was conducted at TUSLHC in quiet clinic rooms by a Temple University speech-language-hearing graduate student. All sessions were recorded.

Treatment Procedures

Script training is the vehicle through which this study was conducted. Robert, an adult with acquired AOS, and the researcher created a functional and practical list of six were used in a planned dialogue with the clinician, meaning that each targeted script phrase was a response to a preselected question that might be asked by a second party in the conversation (the clinician).

Scripts were generated collaboratively between the client and the clinician prior to the collection of baseline measures. Included scripts were deemed functional and relevant to the participant's everyday life. All six scripts consisted of four phrases. Scripts were controlled and balanced for utterance length in number of syllables and number of words. The average number of syllables per script phrase ranged from 5.25 to 9.00, and the average number of words per script phrase ranged from 4.50 to 6.25 (see Appendix A). None of the pairwise comparisons between scripts (using two-sample t-tests) were significant for either average number of syllables or average number of words per script (all $p > 0.05$). Each of the six conversational scripts included clinician prompts (e.g., questions) to provide a simulated functional context (Cherney, Kaye, & van Vuuren, 2014; Youmans et al., 2005; see Appendix A).

After generating and balancing scripts, the list of six scripts was randomly split into three sets (a self-controlled feedback set, a clinician-controlled feedback set, and an untreated control set) via a random number generator in Microsoft Excel. Randomization resulted in the following script sets: untreated control scripts were scripts 3 (Hoagies) and 4 (Modell's); scripts receiving self-controlled feedback were scripts 2 (At the Deli) and 5 (Personal Information I); and scripts receiving clinician-controlled feedback were scripts 1 (Ordering Coffee) and 6 (Personal Information II). It should be noted that the participant had experience with script training from previous therapy. Scripts from current treatment were unique from previously practiced scripts, with overlap occurring minimally with script 1 (Ordering Coffee).

Procedures included a cueing hierarchy in order to reinforce new script learning (Youmans, Holland, Muñoz, & Bourgeois, 2005). The hierarchy involved five stages: choral reading of the phrases with the clinician, choral reading with fading support from the clinician, direct imitation of a model, and independent production of the phrase with and without a written cue (Youmans et al., 2005). Treatment was intended to progress through several stages, moving from blocked to more random practice (see *Treatment Protocol* in Appendix B). However, because the study ended prematurely, only stages 1 (targeted across 4 sessions) and 2 (targeted across 4 sessions) were completed. In stage 1, each script phrase was practiced in blocks of four attempts before practicing the next script phrase. Phrases were practiced in order of occurrence in the script. In stage 2, each script phrase was practiced in smaller blocks (two attempts). In stage 3, script phrases would have been practiced once (i.e. the script in its entirety, one phrase at a time). Finally, in stage 4, script phrases would have been practiced in random order. This is repeated for each script. Similar to Youmans et al. (2005), the clinician would have eventually (in stages 3 and 4) begun to vary responses to scripts in order to promote generalization as well as make the scripts more resilient and flexible. This was not able to occur, however.

During the treatment sessions, the participant received verbal feedback for 50% of his trials during each particular session. In stage 1, after the participant produced all four attempts (rather than immediately following each attempt), feedback was provided on two of the attempts. In stage 2, feedback was provided for one of the attempts after the participant produced two attempts. In stages 3 and 4, feedback would have been provided on two script phrases after production of all script phrases. This procedure was motivated by two considerations. First, it was necessary to eliminate confounds between conditions with respect to the timing of feedback (see below). Second, the available evidence suggests that delayed feedback, including summary feedback, promotes motor learning. Motor literature has supported the use of summary feedback (i.e., delayed feedback following a consecutive sequence of tasks) in learning of novel motor skills (e.g., Winchester, Porter, & McBride, 2009; Carnahan, Vandervoort, & Swanson, 1996; Anderson, Magill, Sekiya, & Ryan, 2005). Delayed feedback and summary feedback have also been supported in the speech literature, such as in treatment for AOS (e.g., Adams & Page, 2000; Adams, Page, & Jog, 2002; Austermann Hula et al., 2008).

To implement the critical manipulation (feedback control) and minimize differences between conditions with respect to amount and distribution of feedback across sessions, we implemented the following procedures:

In the self-controlled feedback condition, the participant was asked to indicate on which trials he wanted to receive feedback after producing four (stage 1, 3, and 4) or two attempts (stage 2). In stage 1, the participant indicated two of the four attempts, and in stage 2, the participant indicated one of the two attempts for feedback. External visual cues in the form of laminated pieces of paper numbered 1, 2, 3, and 4 were provided during this time for support (paper numbered 1, 2, 3, and 4 for stage 1; paper numbered 1 and 2 for stage 2). The clinician also utilized the visuals to point and identify the attempt number. This assisted the participant in monitoring his number of productions for a particular phrase, the number of remaining trials he had left, and how much feedback he could request (on either one or two trials, dependent on the treatment stage). Following the production of all trials, the client physically identified the number(s) of the trial(s) on which he wished to receive feedback by pointing at the numbered paper. It should also be noted that the client sometimes indicated he did not have a preference to receive feedback on a particular trial (e.g., when all productions were accurate). In this case, the participant would select a random number with no particular pattern (i.e., he did not consistently select certain trial numbers). Live data was collected during the session by the clinician regarding the participant's performance for all trials (e.g., accuracy of production, prosody, semantic paraphasias, etc.). Data was recorded by the clinician on each trial's performance in order to adequately prepare for provision of feedback for desired trials (following production of all trial attempts). This data was then used to provide specific feedback on the particular trials selected by the participant. Feedback was equally specific for all trials. At no point did the participant indicate that he wanted more/less feedback during treatment.

In the clinician-controlled feedback condition, the clinician attempted to select trials for feedback based on which types of errors appeared to lead to feedback requests in the self-controlled condition, in order to best balance the provision of feedback across conditions. The number of trials that received feedback remained the same across conditions dependent on the stage of treatment (e.g., in stage 1, during the clinician-controlled set and the self-controlled set, feedback was always provided for two out of four attempts). Use of the numbered visuals was also replicated during the clinician-controlled feedback condition, with the clinician pointing to the numbered paper to identify trials. For example, during the self-controlled condition of the large block stage, the participant would point to two of the visuals number one to four to select two trials in which to receive feedback.

In both conditions, the amount of feedback as well as the feedback type were the same. Clinician judgment was based on observed client preferences, in order to best balance and control feedback distribution and manipulation across conditions. For example, the clinician utilized knowledge of performance (KP) feedback more than knowledge of results

(KR) feedback because the participant showed a preference for receiving target-specific feedback over general correct/incorrect feedback. The participant demonstrated excellent self-monitoring skills, and he could recognize when a production was inaccurate. Therefore, specific feedback explicitly detailing the inaccuracy was considered more beneficial to the participant. Feedback was given on inaccuracies including distortions, dysprosody, segmentation, among other errors. Feedback was also considered corrective in that feedback specified not only which sounds were incorrect but also how to make adjustments to productions. This type of feedback was then used during both self-controlled and clinician-controlled scripts. While KP feedback was noted to be preferred by the participant, the use of KP feedback over KR feedback is also supported in the speech motor literature. Mahoney (2019) found KP feedback resulted in greater improvements in treating acquired AOS than KR feedback.

Each session contained both conditions; the order of conditions (self-controlled and clinician-controlled feedback) was counterbalanced across sessions. This was done so that potential effects of fatigue during a session were not consistently associated with the same condition. The first session of the treatment phase was set up so that the client-controlled scripts are treated first, in order to assess participant's preferences for feedback (e.g., KP versus KR). The following sessions then alternated order of conditions accordingly.

Baseline & Probe Procedures

Prior to treatment, baseline measures were obtained through the elicitation of the targeted scripts, including the self-controlled set, the clinician-controlled set, and the untreated control set. Scripts were presented in a random order, but script phrases within each script were presented in order. Each script was elicited in response to oral prompts from the clinician, and there was no cueing or feedback from the clinician following the productions (Youmans et al., 2011). A written cue of the targeted script phrase was provided as needed. The client was permitted to read the visual cue prior to production in order to improve recall of the phrase but was then instructed to flip the visual cue over when reciting the script phrase so as to prevent reading effects on prosody.

Probes of the targeted scripts were administered at the beginning of every other session during the treatment phase. They were administered under the same conditions as the baseline probe – via oral prompts from the clinician (with visual cue of the targeted script provided as needed). Each script was prompted once in a random order, intermixing the self-controlled feedback list, clinician-controlled feedback list, and the untreated control list. As before, within each script, the phrases were elicited in order. Randomization of script order was done via Google's number randomizer. Numbers 1-6 were generated randomly prior to each session and administered as such.

Data Analysis and Predictions

The dependent variables of this study are the accuracy and rate of the scripts produced during probes. Accuracy is the Percentage of Script words used Correctly (PSC), defined as the number of script words correctly produced divided by the total number of words in the script and multiplied by 100 (Youmans et al., 2011; see Appendix C). Following Youmans et al. (2005), alternative word choices and circumlocutions were not accepted as correct because the goal is to automate production of particular phrases. Additional errors that were identified during treatment included the following: substitutions, omissions, distortions, additions, metathesis, stress errors, segmentation, and overall unintelligibility (see Appendix C). It should be noted that both motor speech errors (e.g., prosody and distortion) as well as aphasic errors (e.g., semantic paraphasias, perseverations) were counted as errors in analysis of accuracy. The script is to be produced verbatim. Rate was defined as the number of communicative words (excluding non-communicative repetitions of words or phrases and excluding interjections) per minute (WPM; Youmans et al., 2005, 2011; see Appendix C). Both dependent measures were obtained by an independent rater based on analysis of probe audio recordings. Attempts were made to blind the listener, such as randomizing the probe audio files prior to analysis. However, due to the effects of COVID-19, the independent rater cannot entirely be deemed a blind listener, as the listener took part in cropping the audio files in preparation for analysis (due to inability to recruit multiple independent raters because of COVID-19's lockdown measures).

Data was plotted for visual analysis. Final analysis (comparison of conditions) was based on effect size (*d* statistic; Beeson & Robey, 2006; Busk & Serlin, 1992). This was intended to be calculated by utilizing scores from both pre- and post-treatment assessments via the following formula: [$(score_{post} – score_{pre}) / SD_{pre}$]. Effect size aims to quantify the difference between averaged final scores of accuracy and rate of scripts (post-treatment) and averaged initial scores (during baseline) relative to initial baseline standard deviation scores of accuracy and rate of scripts. Because post-treatment data was not collected in this study, data from the last treatment session was utilized as an alternative in the same manner as the post-treatment measures. When analyzing effect sizes, improvement of scripts is considered significant if $d > 1$, meaning that performance from the last treatment session surpasses that of the baseline standard deviation (Maas, Butalla, & Farinella, 2012; McAllister Byun, Hitchcock, & Swartz, 2014).

Hypothesis 1 predicted greater improvement (as indexed by larger effect sizes) for scripts in the self-controlled feedback condition than for scripts in the clinician-controlled feedback condition. Hypothesis 2 predicted the opposite (clinician-controlled feedback > self-controlled feedback). Finally, both sets of treated scripts were expected to show greater improvement than the untreated control scripts.

CHAPTER 3

RESULTS

Percentage of Script words used Correctly (PSC)

PSC measures across the three conditions were plotted for visual inspection (Figure 2). Further breakdown of PSC measures into individual scripts was plotted as well (see Appendix D, Figure D1). Specific effect sizes (*d* statistic) of conditions as well as absolute changes were calculated and analyzed (Table 2).

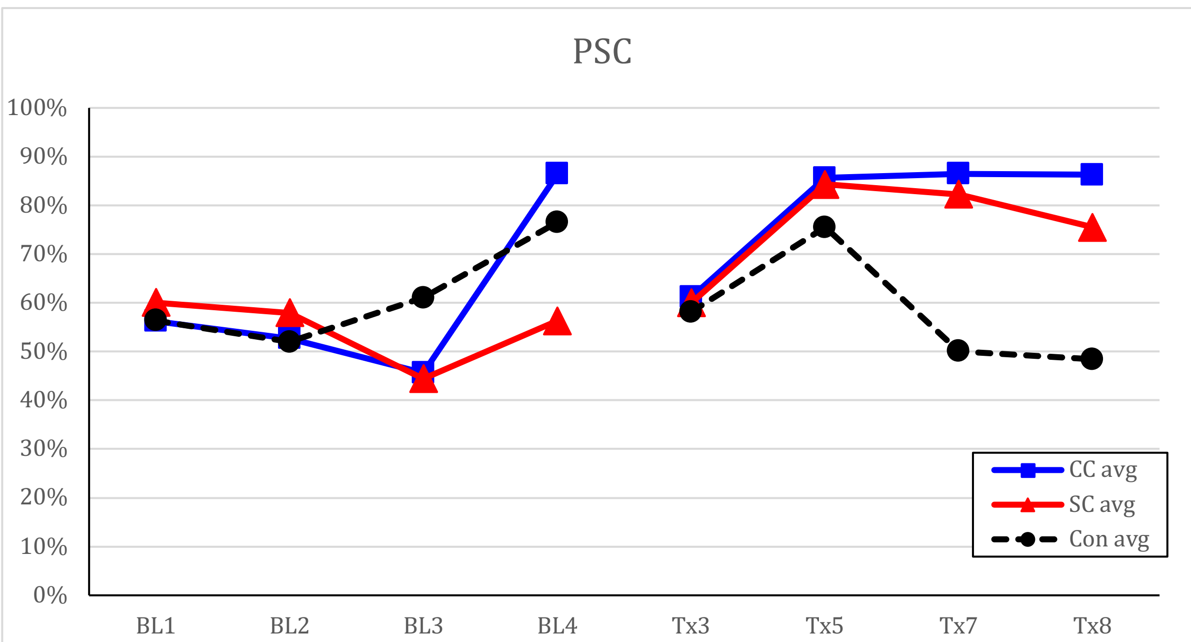

Figure 2. <u>Percentage of Script words used Correctly (PSC) across all conditions.</u> Averages of script performances dependent on condition were calculated and plotted. CC avg. represents clinician-controlled scripts averages, SC avg. represents self-controlled scripts averages, and Con. avg. represents the untreated control scripts averages.

Condition	Effect Size (*d* statistic)	Absolute Change between Avg. Baseline and Final TX Session
Clinician-controlled FB	1.44	26%
Self-controlled FB	2.96	20.8%
Control	-1.22	-13%

Table 2. PSC effect sizes and percent change across conditions.

Visual inspection of plotted data revealed baseline measures that were relatively consistent across conditions. For the majority of baseline measures, there was little difference observed between the PSC of baselines for the clinician-controlled, self-controlled, and controlled sets. It should be noted that there was an increase of accuracy for the final baseline measure of the clinician-controlled set. This was then observed to decrease at the beginning of treatment, indicating that it was not an improving trend but that the performance across baseline measures of the clinician-controlled scripts was unstable. The same pattern was evident for the untreated control scripts, albeit with a smaller increase on the last baseline.

At the beginning of treatment (i.e., TX3, after only two treatment sessions), all conditions began with similar PSC (60% +/- 2% accuracy). Following a notable increase of performance across the three conditions for TX5, a clear divide was then established between the treated sets and the untreated control set. As treatment progressed, this clear difference in the accuracy of productions was maintained throughout the last probe (TX8). The increase observed for the untreated control condition at TX5 was not sustained, and accuracy decreased to slightly below baseline levels throughout the last probe. The treated conditions (clinician-controlled and self-controlled) maintained their gains or slightly increased for the remainder of treatment. Treated conditions demonstrated differences as well. In regard to the clinician-controlled set, though accuracy increased across treatment, it did not surpass the highest accuracy achieved during baseline performance. For the self-controlled set, however, PSC significantly increased beyond baseline accuracies, suggesting a positive treatment effect.

Effect sizes of the treated conditions confirmed these observations. Effect size (*d*) of the clinician-controlled set was 1.44, and effect size (*d*) of the self-controlled set was 2.96, whereas effect size for untreated control scripts was -1.22. Thus, only the treated conditions showed significant positive effects, and the self-controlled set's effect size was numerically greater than that of the clinician-controlled set. This difference indicates that the self-controlled condition made gains during treatment that surpassed its baseline measures. While the clinician-controlled set also made gains that were greater than the baseline standard deviation, it was not as substantial as the self-controlled scripts due to its less stable performance during baseline.

Communicative Words per Minute (WPM)

WPM were tracked across the three conditions and then plotted for analysis (Figure 3). Measures were further broken down into individual scripts and plotted as well (see Appendix D, Figure D2). Condition effect sizes (*d* statistic) and absolute changes were calculated and analyzed (Table 3).

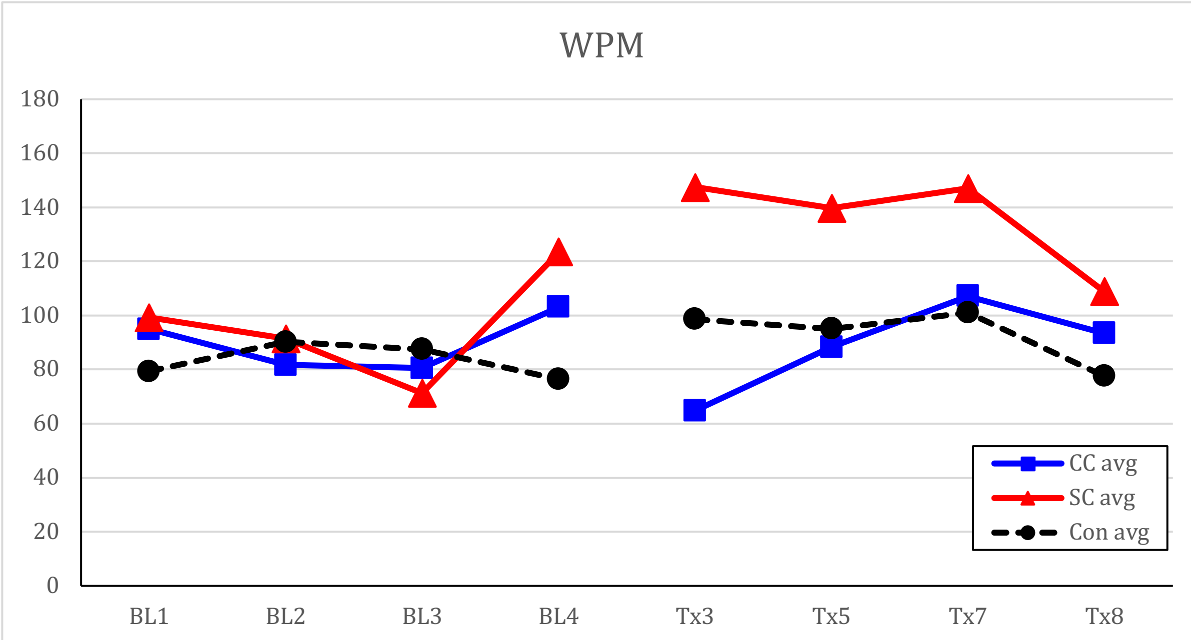

Figure 3. Words per Minute (WPM) across conditions. Averages of script performances dependent on condition were calculated and plotted. CC avg. represents clinician-controlled scripts averages, SC avg. represents self-controlled scripts averages, and Con. avg. represents the untreated control scripts averages.

Condition	Effect Size (*d* statistic)	Absolute Change between Avg. Baseline and Final TX Session
Clinician-controlled FB	0.31	3.4
Self-controlled FB	0.58	12.5
Control	-0.89	-5.8

Table 3. WPM effect sizes and change cross conditions.

Analysis of baseline measures of WPM demonstrated minimal variability across the three conditions, with the exception of increased rate for the final baseline measure of the self-controlled condition. However, WPM measures of the self-controlled set were observed to maintain well above baseline measures throughout most of treatment (regression of rate was not observed at the beginning of treatment). During treatment, a divide between conditions was clear: the self-controlled set had increased WPM compared to baseline measures while the clinician-controlled and untreated control sets did not experience rate of speech substantially above their baseline performance. While WPM of the control set did increase at the beginning of treatment, a gradual decrease of WPM below baseline performance was then observed for the remainder of treatment. For the clinician-controlled set, WPM of scripts during treatment remained within similar range of baseline measures. For both the controlled set and the clinician-controlled set, performance indicated that there was no treatment effect for either condition. Based on the performance of the self-controlled set during treatment compared to baseline measures, however, there is the possibility of treatment effect for this condition. For the majority of data collected during treatment, the WPM of the self-controlled condition were higher than performance during baseline, although there was a decline on the last probe. While no effect sizes across conditions were greater than 1, the self-controlled set was noted to have the largest effect size.

CHAPTER 4

DISCUSSION

This study primarily sought to assess the relative efficacy of self-controlled feedback versus clinician-controlled feedback in treating adults with acquired apraxia of speech. A secondary goal was to evaluate if script training therapy, developed by Youmans et al. (2005) for aphasia and first applied specifically to AOS by Youmans et al. (2011), is a viable treatment method for adults with AOS.

Feedback Control Conditions

The manipulation of feedback control has not been previously evaluated for its efficacy in AOS treatment or in speech motor learning in general. This is the first study to assess self-controlled feedback versus clinician-controlled feedback in the speech motor literature. While clinician-controlled feedback in clinical practice is likely the standard of the field, results from this study indicate that self-controlled feedback has greater efficacy in increasing accuracy and potentially more efficacious in increasing rate of speech in adults with AOS than clinician-controlled feedback. The self-controlled feedback condition had larger effect sizes for both dependent variables (percent accuracy and rate of speech), with the effect size for the percent accuracy variable being statistically significant according to our definition ($d > 1$). In regard to percent accuracy, the self-controlled set of scripts increased in accuracy of productions well above baseline measures, which is interpreted as a treatment effect. For rate of speech, the self-controlled condition was the only condition to surpass baselines measures during treatment in rate. Because of the upward trend beginning prior to treatment, however, this cannot be confirmed as the sole reason for the increase of accuracy during treatment. In addition, though the participant did not speak on this explicitly, the participant appeared more engaged during the periods of the session when the self-controlled condition was implemented. This was evident by the participant leaning in during the self-controlled feedback condition and leaning back in his chair during the clinician-controlled condition. The participant also demonstrated enthusiasm when directed to select desired trials for feedback. These observations support the notion that self-controlled feedback is more engaging and motivating for the participant, as he/she is directly involved in provision of feedback.

In terms of the clinician-controlled condition, performance during treatment for both dependent variables did not increase above the highest baseline probe, although it did exceed the baseline average for percent accuracy. For percent accuracy, the clinician-controlled set's effect size was statistically significant, but because a baseline measure was the same as the majority of treatment measures, performance was considered unstable. Nevertheless, all treatment probes were above the baseline probes except for the last baseline probe. The fact that accuracy on the first treatment probe was well below the last baseline probe suggest that the increase on the last baseline probe did not reflect a sustained improving trend. As such, the sustained improvement on later treatment probes likely indicates an effect of treatment. For the rate of speech variable, rate during treatment did not significantly surpass rate during baseline, indicating that there was no treatment effect for the clinician-controlled condition.

Overall, during treatment, the scripts that received self-controlled feedback improved in accuracy and rate from baseline measures more than the scripts that received clinician-controlled feedback. These results suggest that self-controlled feedback may increase efficacy of treatment for individuals with AOS and may be more beneficial in clinical practice than the standard clinician-controlled feedback. These findings are consistent with those observed in the nonspeech motor learning literature (e.g., Wulf, 2007), and add another principle of motor learning to the growing body of research indicating that such principles hold relevance for treatment of motor speech disorders such as AOS (e.g., Austermann Hula et al., 2008; Knock et al., 2000; Wambaugh et al., 2017). It should be noted, however, that the participant had aphasia that impacted accuracy and rate of script productions. Because of this, the effects of treatment cannot be easily teased apart or ascribed to gains in language (e.g., word finding) or speech motor planning with these dependent variables. Future research addressing analysis of specific error types would help shed light on this.

Replication of this study in full is needed given the alterations made to the intended methods of the study due to COVID-19. For example, it is important to evaluate the durability of the gains by obtaining follow-up measures. It is also possible that stronger condition differences (including for rate of speech) would be observed had the study been completed as intended. In addition, it would be beneficial to replicate the study with a greater number of participants.

Script Training

This study also served as a replication of Youmans, Youmans, and Hancock (2011)'s study supporting script training as a successful and functional treatment for clients with AOS. The participant and the graduate student clinician created personal and relevant scripts that the participant deemed functional in his everyday life. Two scripts were used as an untreated control set in the study to assess the difference between treated and untreated scripts following treatment. For both dependent variables of this study, the untreated control scripts were noted to have negative effect sizes while treated scripts all had positive effect sizes (i.e., treated scripts experienced an increase of accuracy and rate for the most part). It is unclear why the untreated control scripts showed a small decline in accuracy over the course of treatment. Recall that scripts were matched and developed on the basis of personal functional relevance, and then randomly assigned to conditions to avoid any systematic bias. It should also be noted that the participant did not express any preference for one script over another, as they were all developed to be equally functional and relevant for the participant.

Taken together, the pattern of findings across conditions indicates that script training is an efficacious method of treating adults with AOS, with both treated conditions showing a treatment effect for accuracy, albeit more robust effects for the self-controlled feedback condition. The lack of clear treatment effects for speaking rate may be due to the fact that the treatment was discontinued prematurely due to COVID-19. Overall, these findings provide an important replication of the efficacy of this treatment approach for individuals with AOS. The participant's familiarity with script training, however, may have had an impact on this outcome.

CHAPTER 5

CONCLUSION

Clinician-controlled feedback in speech therapy is the standard or default during clinical practice based on clinician expertise and experience. The present study is the first to assess the effects of manipulating feedback control in the speech motor literature. The motor learning literature has established that self-controlled feedback is more efficacious in treatment than clinician-controlled feedback. This study suggests the same: self-controlled feedback is more efficacious in treating adults with AOS than clinician-controlled feedback. Improvements are noted especially in accuracy of productions and have the potential to impact rate of speech as well. Replications of this study are needed in order to address the impact that COVID-19 had on the present study’s treatment schedule. Finally, the present study provides a controlled replication of the efficacy of script training for AOS.

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APPENDIX A: SCRIPTS

Phrase #	Prompt	Script Phrase	# of Syllables	# of Words
1	Hello.	Hello.	2	1
2	What can I get for you?	A hot large dark roast coffee with cream and sugar – senior discount.	16	12
3	Anything else?	That's all. Thank you.	4	5
4	Are you order number XX?	Yes, that's me.	3	4
		Total	25	18
		Average	6.25	4.50

Table A1. Script 1 – Ordering Coffee. Clinician-controlled feedback.

Phrase #	Prompt	Script Phrase	# of Syllables	# of Words
1	How can I help you?	Could I have a half pound of ham?	8	8
2	Yes. Is that all?	Which cheese is on sale?	5	5
3	(CHEESE)	I'll take a quarter pound.	6	6
4	Anything else?	That's all.	2	3
		Total	21	22
		Average	5.25	5.50

Table A2. Script 2 – At the Deli. Self-controlled feedback.

Phrase #	Prompt	Script Phrase	# of Syllables	# of Words
1	What can I get for you today?	I'd like the Italian diablo.	10	6
2	Mayo, or oil and vinegar?	No mayo – oil and vinegar.	8	5
3	What else?	Salt, pepper, onions, tomato, and lettuce.	11	6
4	Anything else?	Some hot peppers on the side.	7	6
		Total	36	23
		Average	9	5.75

Table A3. Script 3 – Hoagies. Controlled.

Phrase #	Prompt	Script Phrase	# of Syllables	# of Words
1	That will be 15 dollars.	I'm sorry, that can't be right.	7	8
2	What's wrong?	I took that shirt from the sale rack.	8	8
3	What was the price?	It said ten dollars.	5	4
4	I will call a supervisor to change the price for you.	Thank you.	2	2
		Total	22	22
		Average	5.5	5.5

Table A4. Script 4 – Modell's. Controlled.

Phrase #	Prompt	Script Phrase	# of Syllables	# of Words
1	Can you spell your last name?	XX	7	7
2	What's your address?	XX	14	8
3	Okay.	Can you repeat it back to me?	8	7
4	XX	That's right.	2	3
		Total	31	25
		Average	7.75	6.25

Table A5. Script 5 – Personal Information 1. Self-controlled feedback.

Phrase #	Prompt	Script Phrase	# of Syllables	# of Words
1	What's your zip code?	XX	5	5
2	Your phone number?	XX	12	10
3	Last four digits of your social security number?	XX	5	4
4	Thank you.	Have a nice day.	4	4
		Total	26	23
		Average	6.5	5.75

Table A6. Script 6 – Personal Information 2. Clinician-controlled feedback.

APPENDIX B: TREATMENT PROTOCOL

Script Phrase	Target Phrase	Attempt	FB?	Controlled FB Type	Accuracy	Cue Type
Stage 1: Large Block						
1		1				
		2				
		3				
		4				
2		1				
		2				
		3				
		4				
3		1				
		2				
		3				
		4				
4		1				
		2				
		3				
		4				

Script Phrase	Target Phrase	Attempt	FB?	Controlled FB Type	Accuracy	Cue Type
Stage 2: Small Block						
1		1				
		2				
2		1				
		2				
3		1				
		2				
4		1				
		2				

Script Phrase	Target Phrase	FB?	Controlled FB Type	Accuracy	Cue Type
Stage 3: Blocked Practice					
1					
2					
3					
4					

Script Phrase	Target Phrase	FB?	Controlled FB Type	Accuracy	Cue Type
Stage 4: Variable Practice					
2					
1					
3					
4					

APPENDIX C: SCORING SYSTEM

Scoring of pre- and post-treatment assessments will be based on accuracy and rate of scripts.

Accuracy Scoring

Blind independent raters will judge the accuracy of scripts based on PSC, which is the following formula: [(number of script words correctly produced / total number of words in the script) x 100]. The number of script words or consonants correctly produced is based on how the produced script phrase compares to the target script phrase. An accurate production is considered to be a word-for-word production of the target script. Speech and language error types that are excluded from the total number of correct productions include:

1. Alternative word choices during an attempt such as using synonyms like “feline” when the intended word is “cat” will not be counted. For example, if a script phrase is, “I would like a hot latte.” and the client produces, “I would like a hot coffee.” all of the words besides “coffee” would be counted toward the PSC.
2. Circumlocutions will not be counted in the PSC. An example of a circumlocution is if the intended phrase were, “I would like a hot latte.” and the client says, “I would like a hot… that drink with caffeine that I put sugar and milk in.” In this example, the words *I, would, like, a,* and *hot* would be counted toward the correctly produced script words. The words following (“that drink with the

caffeine that I put sugar and milk in") would not be included in the final number of script words correctly produced.

3. Speech errors in productions to be aware of include substitutions, omissions, distortions, additions, metathesis, stress errors, segmentation, and overall unintelligibility. If the following errors are produced, the word will not be factored into the total script words that are correctly produced.
    a. Substitutions: exchanging one phoneme (consonant or vowel) for another.
    b. Omissions: missing sounds in words.
    c. Distortions: approximations of a particular phoneme that are not clear or well articulated. Examples include excessive duration of consonants, nasalizing non-nasal consonants, etc.
    d. Additions: adding a sound to a word, such as a schwa.
    e. Metathesis: the exchange or misordering of two words or sounds in an utterance. For example, if the intended word is "pig" and the client produces "gip," the word is not counted toward the total of correctly produced script words.
    f. Stress errors: stress placed on the wrong syllable.
    g. Segmentation: Noticeable pauses between sounds or syllables.
    h. Overall unintelligibility: speech that is not recognizable as a word by the listener.

Rate Scoring

Rate will be defined as the number of communicative words (excluding non-communicative repetitions of words or phrases and excluding interjections) per minute during script production (Youmans et al., 2005, 2011). This measure requires (1) calculating duration of each produced script phrase, and (2) the number of communicative words in each script phrase. Communicative words include all words except interjections, word/phrase repetitions, and unrecognizable words. Examples of interruptions in speech are “yes,” “um,” “uh,” “oops,” etc. Interjections include words that are unnecessary and unnatural in the fluency of speech (Hasseltine, Black, Corcoran, DiPalma, Dixon, … , & Corthals, 2016). Other possible interjections are comments on the script or exclamations, such as “I don’t know!” or “I’m not sure.” Communicative words do not need to be target words in the script (for example, although “feline” would not be acceptable for “cat” for PSC scoring, it *would* be counted as a communicative word for the rate measurement). Contrary to Youmans et al. (2005, 2011), pauses greater than 3 seconds are included in the calculation of duration. Acoustic measurement of rate is based on the following criteria:

1. Start time is considered to be the beginning of a script phrase. The beginning of an utterance includes any whole word repetitions that may occur at the initiation of an utterance. For example, if a target phrase is, “Please may I have a black coffee?” and the client produces, “Please please please may I have a black coffee?,” the onset of the duration measurement is at the beginning of the first “Please”. However, only one “please” would be counted toward the total number

of communicative words.

2. All whole word repetitions are counted only once, regardless of positioning in the utterance (i.e., whether in the initial, medial, and final positions). For duration offset measurement, the end of the last repetition is measured (to be consistent with measurement of repetitions in initial and medial position). For example, if a client says “Please may I have a black coffee coffee coffee” then end of the third “coffee” is taken as the end of the duration, but only one “coffee” is counted for number of words.
3. Words with sound substitutions, sound additions, sound distortions, sound omissions, and/or sound metatheses are counted toward the number of words, as long as the word is recognizable.

APPENDIX D: PSC AND WPM OF INDIVIDUAL SCRIPTS

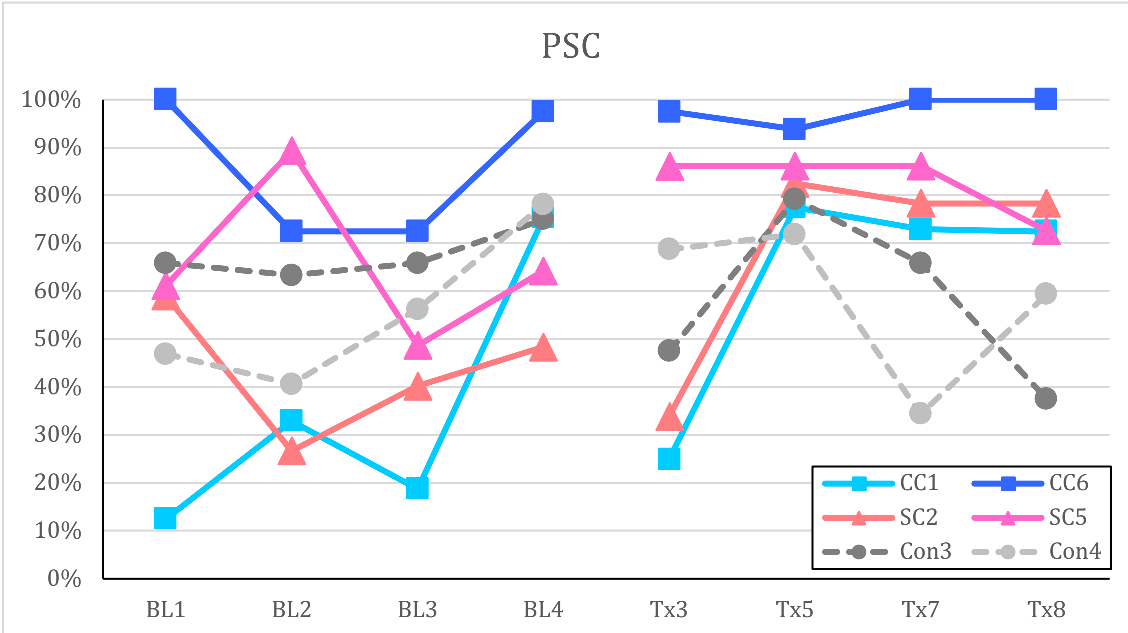

Figure D1. Percentage of Script words used Correctly (PSC) of each individual script.

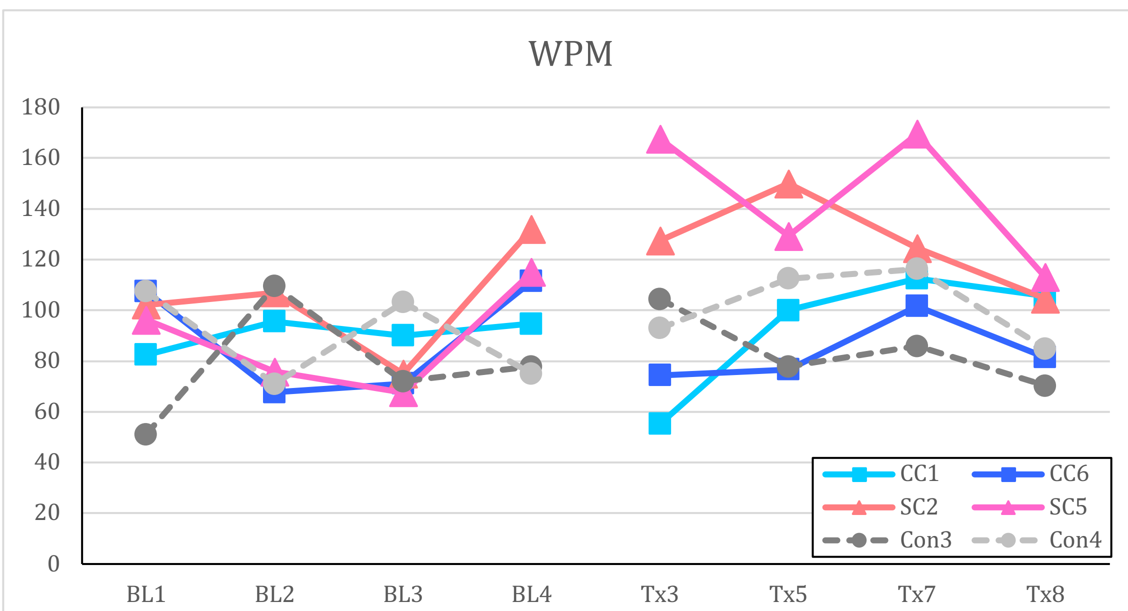

Figure D2. Words per Minute (WPM) of each individual script.