Motor Learning Theory Based Treatment for an Adolescent with CAS: A Single Subject Design

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Abstract: Despite a considerable amount of research on intervention approaches for CAS (childhood apraxia of speech), little work has been done on the effectiveness of motor learning theory based treatment for adolescents with CAS. This study investigates the effect of a motor learning theory based treatment approach on an adolescent with CAS whose severity ranged from mild to moderate. A multiple baseline design across behaviors (target words and sentences) was used in this study. Three sets (20 words for Group 1 and 10 sentences each for Groups 2 and 3) of target stimuli were created (based on high functionality) by the participant and his primary caregiver. The subject was instructed to produce the target word or sentences five times with a 4-second pause between each attempt. Knowledge of results (KR) feedback was given after 5 attempts regarding his performance. The subject repeated each target stimulus 25 times and received 20 % feedback between each trial 5 times. The results showed that the mean scores of speech intelligibility increased during the sessions for target words and sentences and this effect was substantially transferred to untrained target words and sentences.

Keywords: Childhood apraxia of speech, feedback, motor learning theory, speech intelligibility, condition of practice.

1. INTRODUCTION

Childhood apraxia of speech (CAS) is a disorder of motor programming and planning in children that is not associated with muscle weakness [1, 2] It is generally defined as a neurological childhood speech sound disorder and manifests as an impaired ability to carry out the complex motor activities required for speech production not involving neuromuscular dysfunction [3-5]. The term childhood apraxia of speech (CAS) is thought to represent the developmental counterpart of the acquired apraxia (AOS) seen in adults, though significant differences exist [6]. In particular, difficulties with motor planning for speech during the early stages of language and speech acquisition will have an effect on the development of phonology and other language processes [7]. This contrasts with adults with AOS, since the adults have already developed speech and language processes [8]. However, the age of onset and its course have not been clearly documented due to the lack of a consistent consensus on CAS' temporal/ linguistic features [9]. It may also be difficult to describe CAS because of inconsistent articulation symptoms over time and across different ages [10, 5]; a severe articulation disorder is not necessarily a symptom of CAS and a mild speech disorder can turn out to be CAS [10]. Furthermore, some cases may actually consist of phonological disorders misdiagnosed as CAS, or concomitant with CAS [10].

There is general agreement that CAS is a motor programming or planning disorder that shows prosodic impairments, sequencing errors and inconsistency across vowels and consonants, and speech movement difficulties between sounds [3, 8, 11-16]. Contemporary diagnostic criteria for CAS have been proposed [17-18] in the form of 10 segmental and suprasegmental abnormal speech markers indicating the presence of CAS. The authors suggest that individuals with suspected CAS must show at least 4 of these ten abnormal speech characteristics in at least 3 of the Madison Speech Assessment Protocol (MSAP) tasks for a diagnosis in order to distinguish CAS from other similar disorders. The ten abnormal speech characteristics of CAS are as follows: "difficulty achieving initial articulatory configurations and transitions into vowels, lexical stress errors or equal stress, vowel or consonant distortions including distorted substitutions, syllable segregation, groping, intrusive schwa, voicing errors, slow rate, slow diadochokinetic rates, [and] increased difficulty with longer or more phonetically complex words" [17].

According to a recent American Speech-Language-Hearing Association (ASHA) position statement, CAS may be caused by either neurological problems related to a neurobehavioral condition (known or unknown) or

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E-ISSN: 2311-1917/15

an idiopathic neurologic disorder [3]. However, researchers have been unable to identify a consistent correlation between anatomical lesions and the disorder [7, 19-20]. Additional neurological signs such as fine or gross motor delays, abnormal gait, and difficulties of rapid movements have also been reported [7, 21]. In the light of this confusion, severe articulation/ phonological disorder in children has come to be referred to in general as childhood apraxia of speech (CAS) [3, 11, 22].

It is difficult to describe the precise onset of CAS because the exact age of articulatory-phonological development is undefined. Although, the articulatory-phonological abilities of children continue to develop until adolescence [10, 23], information on adolescents with CAS is very limited [24-26] and in spite of experiencing therapy extending over a period of years they frequently complain of continuing difficulty with speech. However, although the nomenclature, nature, and precise characteristics of CAS remain controversial, there appears to be increasing agreement in the literature regarding the underlying motor aspect of the disorder.

1.1. Treatment of CAS

Many different treatment approaches for children with CAS have been attempted [27-29]. Over the years, the principles of motor learning associated with schema theory have received a great deal of attention with regard to understanding human motor learning skills. According to the motor learning literature, the learning of these skills is influenced by factors such as feedback schedule and conditions of practice [30-33]. In addition, how these factors are combined can affect the degree to which newly acquired skills are retained after treatment has ended. Acquisition is taken to mean improved performance during practice and retention is performance level some time later, after practice. Since motor learning has been defined as "a set of processes associated with practice or experience leading to *relatively permanent changes* in the capability for movement" [33], p. 302, the long-term effectiveness of any therapy is thus crucial.

Feedback is an important factor known to affect the learning of motor skills in both adults and children [33-35]. Information regarding the clients' task outcome from the clinician is an important variable that the client relies on to improve their motor skills. Knowledge of results (KR) and knowledge of performance (KP) are the two main forms of feedback. KR represents summary information about the performance of the individual after the task is completed and consists of general information about the performance accuracy, while KP provides far more detailed information regarding a client's performance. In general, KP and KR are both provided in the treatment (acquisition) phase, but KR has traditionally been thought to result in better retention than KP after treatment has ended [36-38]. The motor learning literature indicates that frequent feedback (e.g. after every trial) may result in better motor learning in acquisition, although this is not maintained during retention tasks [39-43]. Providing less frequent feedback has also been reported to improve retention, however. Austermann-Hula *et al*. [40] examined the role of frequency of feedback on motor learning in acquired AOS. Treatment conditions for 4 AOS subjects were counterbalanced within each subject across two treatment phases, with Phase I consisting of less frequent feedback with fricative and more frequent feedback with plosive and Phase II of more frequent feedback with fricative and less frequent feedback with plosive. Their results showed that the less frequent feedback enhanced learning in retention and transfer conditions for two individuals with AOS in the two phases and further analysis revealed a carry over effect to different contexts. However, two other individuals with AOS did not show any significant motor learning under the same conditions for both phases. Similar results have been reported in a CAS study [12], where the authors examined the effect of feedback frequencies in the treatment of four individuals with CAS for the retention and transfer phases. The results showed that two children who received less frequent feedback learned better in the two phases but the other two did not appear to experience any benefit from less frequent feedback. Rather, one of the two children who did not show better learning showed better learning for high frequent feedback, while the other child did not show any specific effect for both phases. The authors concluded that there was a positive effect due to less frequent feedback for children with CAS, but that effect varied depending on their age and/or severity. The effects of immediate feedback and delayed feedback have also been investigated, and several studies have found that delayed feedback is more effective than immediate feedback in the retention and improved learning of motor skills [40, 44-46]. In the second experiment of the study mentioned above [40], 2 AOS subjects who participated in the first experiment had treatment sessions with immediate (within 1 second) and delayed feedback (5 second after the participant's performance) across Phases I and II. The results showed that the immediate feedback condition mostly enhanced the speech acquisition in Phases I and II for two participants. However, the delayed feedback condition enhanced speech learning in retention and transfer. The authors then, concluded that delayed feedback may result in better motor learning in retention and transfer for AOS.

Another important factor affecting the learning of motor skills is the condition of practice. In particular, different types of practice enhance different aspects of motor learning. Blocked practice, where each target is worked separately, is usually effective during acquisition but does not facilitate motor learning in retention. In contrast, random practice, where the targets appear in random order, has been found to be more effective in retention for the learning of motor skills [13, 32, 47-48]. However, according to a CAS treatment study [13] involving four children, one showed better performance for random practice, two showed the opposite results, and the other did not show any improvement in either the retention or transfer conditions. The authors concluded that the effect of random practice in nonspeech motor learning may not be consistently helpful in the treatment of CAS and further studies are needed to assess other factors such as the optimal treatment amount and practice schedule.

This disorder commonly presents with difficulties in motor programming learning, therefore motor learning treatment (MLT) may be a beneficial treatment for individuals with CAS. Repetition is known to be important for motor learning and high frequency practice trials can provide better results for motor learning, particularly speech [30, 49]. Edeal [49] investigated the treatment effects depending on different amounts of practice trials in motor learning. Two individuals with CAS received two differently frequent repetition treatments, high frequency treatment (100-150 practice trials each 15-minsession), moderate frequency treatment (30-40 practice trials each 15- min session) using integral stimulation therapy. The results showed that while both individuals improved their speech intelligibility, their improvement was greater in high frequency treatment. Furthermore, generalization effects to untrained utterances in high frequency treatment were better and more stable than in moderate frequency treatment.

Motor learning principles have been used for the treatment of prosody with individuals diagnosed with CAS [50]; utilizing motor learning principles for the treatment of CAS appeared to improve prosody as well as the maintenance and generalization of the targeted skills.

These principles of motor learning have been involved in developing several new treatments for apraxia of speech (AOS). Friedman *et al*. [51] investigated the effects of modified motor learning principle based treatment to an individual with AOS after traumatic brain injury. Their motor learning treatment comprises blocked and random practice schedules, delayed and KR feedback types, and also consists of three steps to treat two sets of five target utterances. The treatment was effective in acquisition phase and the treatment effects remained in retention phases (1 to 4 months after treatment). However, despite a considerable number of studies on a wide range of intervention approaches for AOS and CAS, little work has been done on the effectiveness and efficacy of motor learning theory based treatment for adolescents with CAS. The purpose of this case study is therefore to investigate the effect of adopting a motor learning theory based approach for an adolescent with CAS. The following research question will be addressed in this study: Is motor learning theory based treatment effective to improve speech intelligibility of an adolescent with CAS?

2. METHODS

2.1. Participant

JM, a fifteen-year old male diagnosed with CAS, voluntarily chose to participate in this study. At the time of the study he was enrolled at a junior high school in Illinois and his mother completed the consent form on his behalf. The participant was born full term at 38 weeks after a non-eventful pregnancy. The participant's mother reported that JM had had no surgeries, seizures, or remarkable medical history and his development was normal, although slower than his brothers. JM began receiving speech/language services at the age of 2 ½ years and these services continued into elementary school. His apraxic speech sounds were first diagnosed by an elementary school speech therapist when he was 8 years old. He also received occupational therapy from Kindergarten through 4^{th} grade for fine motor skills.

2.2. Assessment

The apraxia battery for adults (ABA -2) was used for speech assessment in this study because there are no standardized tests for adolescents. JM was diagnosed as having a mild to moderate apraxia of speech. In a subtest of diadochokinetic rate from ABA-2, JM exhibited slow productions of /pʌtʌkʌ/ and his performance deteriorated in the increasing word length test. In particular, self –correction, audible searching and delayed production were observed during the three –syllable words subtest. JM also had difficulty initiating speech, with abnormal prosodic features (e.g., producing equal stress on each syllable, monotonous prosody on connected speech), fewer errors in automatic speech than in volitional speech, and a receptive-expressive gap from the subtest of inventory articulation characteristics of apraxia. The subject's school speech pathologist (the 2nd author) observed many speech characteristics of apraxia, including difficulties sequencing phonemes and syllables, vowel distortions, intonation and stress inconsistencies, and oral groping movements. Specifically, the types of abnormal prosodic deficits and vowel inaccuracy observed in this study matched those in [3, 17-18]. Further assessments to rule out other possible conditions such as receptive language deficits, dysarthria, and oral structural abnormalities were administered. The oral mechanism screening examination (OSMSE-3) revealed no oral structural abnormalities and JM also showed normal orofacial functioning such as lips, tongue, and jaw movements and normal coughing, swallowing, and velopharyngeal closure. Furthermore, the results of standardized language tests showed that

Table 1: JM's Scores on Language Assessment Tests

Clinical Evaluation of Language Fundamentals-4 (CEFF-4)	Standard score
Core Language	78
Receptive Language	98
Expressive Language	75
Language Content	94
Language Memory	80
Peabody Picture Vocabulary Test-III (PPVT-III)	88
Expressive One Word Picture Vocabulary Test (EOWPVT)	82
Expressive Vocabulary Test	78

Table 2: JM's Scores on Subtests of the Apraxia Battery for Adults-II

Subtest	Raw score	Level of impairment
Diadochokinetic Rate	5	Moderate
Increasing word length (1)	5	Moderate
Increasing word length (2)	3	Moderate
Limb apraxia	49	None
Oral apraxia	49	None
Utterance time for polysyllabic words	23	Mild
Repeated trials	16	Mild
Inventory of articulation characteristics of apraxia	10	

his receptive language was in the average range compared to his peers, while his expressive language fell well below the mean. The scores for each language test and the results for the subtests of the ABA-2 are provided in Tables **1** and **2**, respectively.

2.3. Design

A multiple baseline design across behaviors (target words and sentences) was used in this study. The accuracy of produced words and sentences (intelligibility scores) served as the dependent variable. Treatment sessions were conducted twice a week over a period of 10 weeks for 20 sessions. Two sets (20 utterances each) of stimuli for 2 to 5 syllable words were created by the participant, his school SLP, and his primary caregivers. One set of stimuli was utilized for treatment and the other set was measured every 2nd to 3rd session to look for generalization. Two sets (10 utterances each) of stimuli for 5 to 6 words and for 7 to 11 word sentences were created for the treatment. Again, one set of stimuli was utilized for treatment and the other set (untreated) was utilized to look for generalization at every 2nd to 3rd session. The first baseline was stable over two weeks (4 sessions). After the first two weeks, the treatment was implemented for 2 to 5 syllable words. When 2 to 5 syllable word targets were 80 % mastered before ending treatment, the next sentence level treatment was started. These target words were treated for eight weeks. In Week 5, the treatment was implemented for the second baseline (5 to 6 word sentences). These target utterances were treated for 5 weeks. The other set of these target utterances was used at every 4th session to look for generalization. The 2 to 5 syllable words on the first baseline continued to be treated with 5 to 6 word sentences. Finally, in Week 8, the treatment was extended to 7 to 11 word sentences. The treatment was maintained to week 10. The other set of these target utterances were used at every session to look for generalization. For the baseline, JM produced all the target utterances using the written cards provided by the experimenter before the pre-practice session. The list of target words and sentences is shown in Table **3**. Six of the sentences have been removed because they contain potentially identifying information.

2.4. Treatment

The treatment procedure was based on a motor learning guided approach developed by Hageman *et al*. [52]. This treatment protocol incorporates reduced frequency of feedback, delayed feedback, random practice, and a considerable amount of target repetition. The developers compared the effect of this treatment approach to that of melodic intonation therapy on speech in apraxia of speech patients (AOS) and reported that the AOS patients receiving the motor learning guided approach showed a better performance than those receiving melodic intonation therapy. An

Table 3: Target Word and Sentence Groups

	Trained items	Untrained items
Phase 1 (2-5 syllable words)	Catholic, Gondola, Rumble, Royal, Halloween, Groceries, Wisconsin, Spaghetti, Neighborhood, Paragraph, Rivalry, Avanti's, Burrito, Experience, Education, Comprehension, Constitution, Appropriate, International, Inappropriate,	Pirates, Wrestle, Olympics, Popular, Wrestling, Graduate, Exponents, Performance, Understand, Meaningful, Charleston, Entertainment, Secretary, Transportation, Harry Potter, Conversation, Caribbean, Babysitting, Immediately, Electricity,
Phase 2 (5-6 word sentences)	Eight grade is now over. My brothers can drive a car. I will learn to drive soon. You must be quiet in church. That math problem is simple. People from England are British. Sometimes, I babysit for my cousins. Chipotle has the best chicken burritos. [2 sentences deleted.]	Spring is my favorite season. May is my favorite month. The sun is shining this afternoon. P.E stands for physical education. I will be in ninth grade. I ate chocolate ice cream today. The Blackhawks are in the playoffs.[3 sentences deleted.]
Phase 3 (7-11 word sentences)	We will go to Virginia this summer. The Colts football team is from Indianapolis. I watched an episode of America's Most Wanted. I watch the show Degrassi on Teen Nick. Obama is the president of the United States. Matt lives in West Dundee Illinois close to Chicago. You need to understand these pages for the test. The population tells us how many people live in an area. My dog is a black lab mixed with a golden retriever. [1 sentence deleted.]	I need to pay attention in class. You need to act serious in church. I never cause my parents any problems. Brian Urlacher plays for the Chicago Bears. I ordered a Big Mac at McDonald's restaurant. There was a large audience watching the speech. Do you like to watch wrestling on Monday nights? We are reading a new story in language arts. There are several pieces of candy in the candy jar. When you find the important words in sentences, underline the words.

Note: All sentences including information specific to the subject have been deleted from this table.

additional five minute pre-practice period was included in each session in order for the subject to understand the purpose of the study, what a correct response is, and what the feedback used means. The experimenter practiced modeling the target utterances with JM, who received detailed feedback (KP) regarding his speech production to help him produce correct speech sound during practice without models (an example of this could be “your tongue is too far forward”). Verbal instructions in pre-practice are useful and important regarding articulatory movement [33] and also provide the subject with a chance to practice the target utterances that will be used in the upcoming treatment session.

Once JM had produced the target utterances at least five times correctly, the practice session (therapy) was started. For the initial step, all the written target utterances were randomly mixed and the experimenter and JM produced one of the target utterances simultaneously. When the produced target utterance was wrong, they continued to say it together. JM then attempted the utterance 5 times with a 4-second pause between each trial. After 5 trials, the experimenter repeated and modeled the utterance, waited 4 seconds and provided KR (knowledge of result) regarding his 5 trials. This step continued for each block of 5 target utterances. For the second step, the only difference from the initial step was that the experimenter produced the utterance, waited 4 seconds and the utterance was presented from a written stimulus card in random order. JM then produced the target utterance 5 times with a 4-second pause between each trial, after which the experimenter repeated the target utterance and provided KR regarding his 5 trials. In the next step, no models were provided and the target utterance was simply presented from a written stimulus card in random order; JM produced the utterance 5 times and received feedback from the experimenter following the same procedure as in the previous steps. After Step 3, JM was allowed to take a 2-minute break if needed. After training on a block of 5 target utterances, Steps 1 to 3 were repeated for another block of 5 target utterances until all 20 of the target utterances had been completed. For the next step (Step 4), each of the 20 written stimulus cards were randomly presented and JM produced the utterance 5 times, with a 4 -second pause between each trial. Then, the experimenter provided KR feedback regarding his 5 trials. For the final step, Step 4 was repeated to gain more speech production. For the other target utterances, 10 additional sentences were practiced during each treatment session from the 11th session onwards. For the current study, each step was altered slightly and Step 5 added to elicit more speech production. (See Appendix 1)

Overall, during the treatment session the participant produced each target word 25 times. The experimenter provided KR after JM had produced each target utterance 5 times, with a 4-second pause between each trial 5 times (20% feedback). A group of untrained target utterances were then probed randomly to look for any transfer effect, as described in Section 2.3

Each treatment session occurred in a quiet treatment atmosphere that was as free from distraction as possible. JM was instructed to refrain from asking questions during the practice and, more importantly, asked to refrain from talking during the post KR delay interval. The multidimensional scoring system developed by [52] was used by two raters to score the accuracy of the participant’s speech production on an 11-point scale (see Appendix II). Inter-rater agreement was carried out for a randomly selected 20% of trials across the three target utterance groups after treatments and was measured as 85% by the second author.

3. RESULTS

The results are shown in Figure **1**, which shows the intelligibility scores about one week after each treatment.

Baseline measures for 2-5 syllable target words were collected over four sessions and JM’s performance was relatively stable. Performance of the 2 to 5 syllable words improved overall during the first treatment phase. The mean scores from treatment session 1 to the final session for 2-5 syllable target words increased from 6.5 to 10.3. A similar effect for untreated target words was observed through sessions 8, 10, 12, 14, 17, and 20. The mean scores for the twenty untreated words also increased, from 6.4 to 10.1.

Treatment phase 2 for 5-6 word sentences commenced after the 10th session. Interestingly, the baseline from sessions 5 to 10 was far less stable than the previous baseline for target words alone. However, this is considered a generalization effect from 2-5 syllable target words to 5-6 word sentences (sessions 5 -10) during baseline and this treatment effect generalized to the baseline (7-10) of 7-11 word

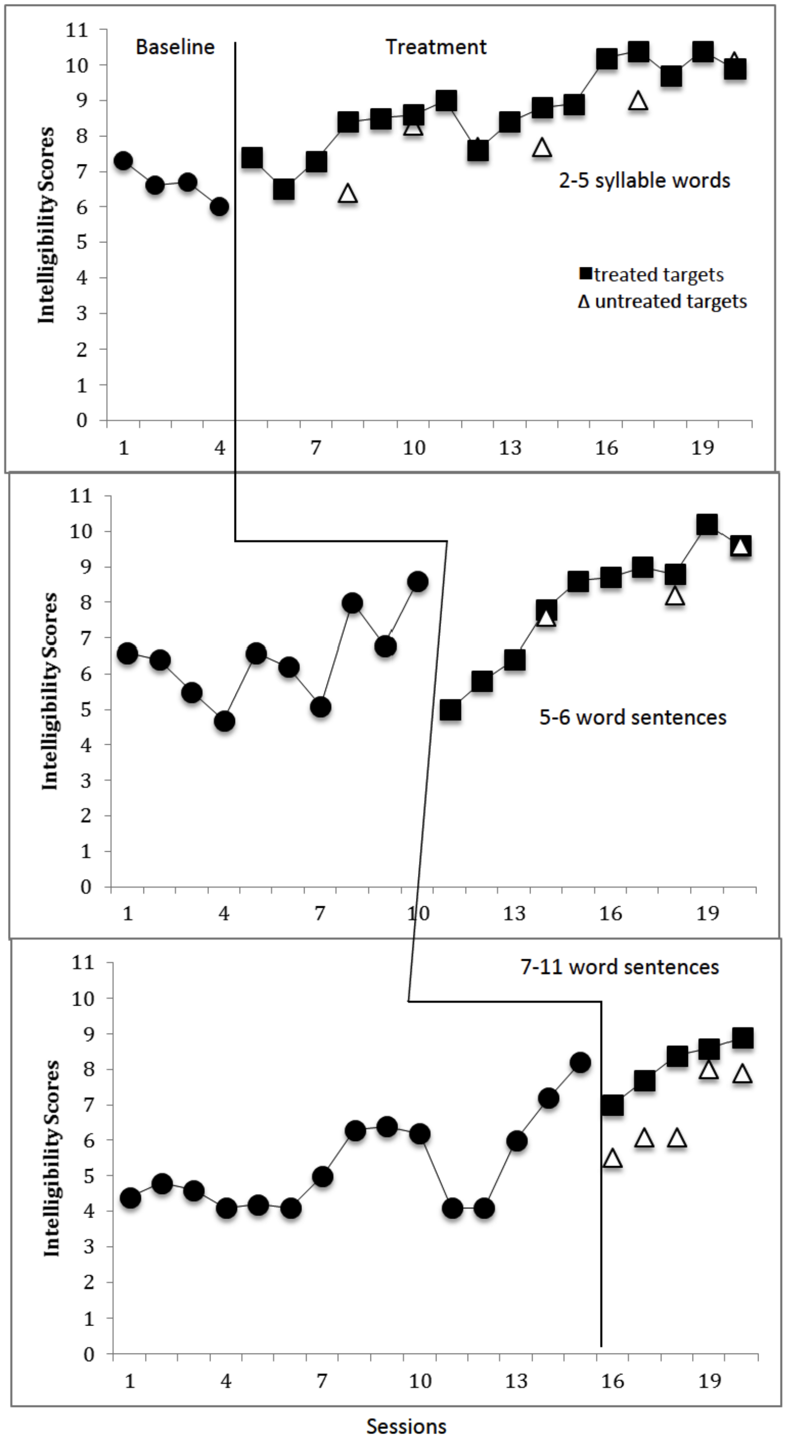

Figure 1: JM's intelligibility scores across target words and sentences for 20 sessions.

sentences as well. Mean scores of the beginning of the phase 2 dropped below the baseline for session 11. However, the mean scores then steadily increased from 5 to 10.2 between that session and the final session. Performance on untreated target sentences also improved from 7.6 to 9.6 between sessions 14 and 20.

JM received treatment for 7-11 word sentences from session 16 to session 20 (treatment phase 3). The baseline from session 12 to session 15 was irregular, and did not demonstrate consistency. However, this is considered a similar generalization effect observed in 5-6 word sentences. So, single word treatment effects generalized to 7-11 sentences (sessions 6-10) during baseline. Furthermore, when 5-6 word treatment sessions were given, the treatment effects from combined 2-6 syllable words and 5-6 word sentences generalized to 7-11 sentences (sessions from 12 to 15) during baseline. The mean scores for the treatment sessions for 7-11 word sentences did not increase as much as for 2 to 5 syllable words and 5 to 6 word sentences, although they did rise slightly from 7 to 8.9. The mean scores for the untreated target sentences increased from 5.5 to 7.9 over the five treatment sessions.

Taken together across the three target utterance groups, the mean scores for speech intelligibility consistently increased. In particular, the 2-5 syllable target group saw a considerable improvement, with mean scores rising from 6.5 to 10.3 as a result of applying the motor learning theory based approach. The mean scores of the other two target utterance groups also increased, although the scores dropped immediately after the first therapy session on both groups. Also, the mean scores of untreated items on the three target utterance groups were considerably higher and these scores were maintained over later treatment sessions.

The adolescent with CAS showed a marked improvement in his speech production of 2-5 syllable targets after receiving the motor learning theory based treatment. In particular, the mean scores from the baseline to the final probes for two to five syllable words increased to over 10. A generalization effect was also evident in untrained target words, where intelligibility also increased to 10.1 by the end of the last treatment session. Improvement was documented after the third treatment session for five to six word sentences and the mean intelligibility scores stabilized at up to 9.6 after the last session. There was also some evidence of a generalization effect for the untrained target sentences, whose mean intelligibility scores climbed to 9.6 even without receiving the treatment. The treatment cannot be proven effective for five to six word sentences, however, due to the unstable baseline and a decrease of accuracy after the first treatment session. Fluctuations were observed in the baseline after the 4th session when the first treatment session for the 2 to 5 syllable words occurred. Treatment of 2 to 5 syllable words may have impacted the participants productions of 5 to 6 word sentences, which would result in the increased intelligibility score of 5 to 6 word sentences observed during the fifth baseline session. A similar phenomenon occurred with the 7 to 11 word sentences. The baseline was again unstable, demonstrating an increase of accuracy before treatment of 7 to 11 word sentences occurred and then a decrease in accuracy after treatment was initiated. The intelligibility scores dropped from 8 at baseline to 7 after the first treatment session. However, the mean scores during the treatment sessions for 7 to 11 word sentences steadily increased from the second to last treatment sessions.

4. DISCUSSION

The aim of this study was to investigate the effect of motor learning theory based approach on speech motor learning for a fifteen year old adolescent boy with CAS using a multiple base line design across behaviors (target words and sentences) over 20 sessions. The results obtained for this study are mixed and not in complete agreement with those of other studies [13, 49-50]. The reason for the significant decrease in accuracy at the beginning of treatment from baseline for 5 to 6 word sentences and 7 to 11 word sentences is unclear. However, according to the second author's report, JM was emotional at the beginning of the eleventh session and during the sentence trials he made many self-corrections and frequently added and omitted words. This may explain the very low mean score for the beginning of 5 to 6 word sentence targets after the first treatment session and decrease of accuracy observed at the baseline session for 7-11 word sentences. However, JM's emotional distress did not seem to affect the 2-5 syllable target words at the same session, possibly because the target words were trained enough to be automatized to the motor speech system. The second author did not report any external or internal forces that could disrupt JM's performance on 7 to 11 word sentences. Other possible explanations for the significant decrease in accuracy at the beginning of this treatment includes factors such as a cognitively more demanding task, the shift in focus, or the sudden change in the level of difficulty due to the introduction of new tasks or stimuli [53-54]. For example, according to [54], the effects of sound production treatment (SPT) for AOS at the word level decreased when the same treatment was applied in the context of sentence completion. The authors concluded that the task of word production at the sentence level was more demanding than a simple word repetition task. They also noted that the maintenance effect decreased in previously learned target sounds as a result of shifting the focus from one task to another. Therefore, the significant decreases in accuracy observed for the second and third treatment phases in the current study may reflect the sudden change in stimuli difficulty experienced on moving from the word level to the sentence level. The fluctuations in the baseline scores between sessions 12 and 15 may be due to the effect of the previous treatment on the 5-6 target words. It is possible that the complexity of the 5-6 word sentences was close enough to that of the 7-11 word sentences to interfere with the baseline measurement based on the fairly similar pattern of the mean score increases for these sessions. Furthermore, the complexity of the two target groups (5-6 word sentences and 7-11 word sentences) was not distinct enough to enable us to discriminate between the treatment effects. With hindsight, using 5-6 word sentences and 10 to 11 word sentences instead of 7 to 11 word sentences would have allowed the researchers to discriminate the results of treatment more accurately.

The data from this study suggests motor learning theory based therapy may be effective for 2 to 5 syllable words but the effectiveness of this treatment on the acquisition of sentences cannot be determined due to the inconsistent baselines and decrease in accuracy upon treatment for sentences.

Overall, although a positive effect was observed for 2-5 syllable target utterances and in part for the other two groups of the target utterances, JM's improvement on 5 to 6 word sentences and 7 to 11 word sentences was minimal compared to the improvement shown for 2 to 5 syllable words. This result is partially consistent with a previous AOS treatment study, where reduced delayed feedback was not effective on complex stimuli for some participants [40]. Those authors suggested that adjusting the type of feedback alone was insufficient to outweigh stimulus complexity on both the retention and transfer phases. In our study, JM showed better performance on less complex target utterances (2-5 syllable words). However, our finding of less generalization for untrained target utterances on 7-11 word sentences (complex stimuli) than for 2-5 syllable words (less complex stimuli) is not consistent with reports that practicing more complex utterances enhances the transfer effect for unfamiliar utterances [34, 55-56]. In conclusion, our findings support the efficacy of utilizing a motor learning theory based approach in adolescents with CAS for 2 to 5 syllable words, but this study cannot support the efficacy of utilizing a motor learning theory based approach for the acquisition of sentences and complex stimuli.

Some limitations of this study should be noted. The first limitation affecting this study is the lack of post-treatment retention (i.e. a follow-up phase) since including it in a multiple baseline study is more meaningful for demonstrating long-term treatment efficacy. Another weakness is the lack of an experimental control for the apparent generalization effect across the two untreated target groups during the single word treatment, and subsequent generalization from 5-6 word to 7-11 word sentences. Other limitations of the current study include the relatively short treatment periods for the two target sentence groups and the lack of a clear distinction between the complexity levels of the two target sentence groups. Future research on motor learning based treatment for adolescents with CAS for the acquisition of sentences is therefore needed. It would be particularly helpful to examine multiple participants as well as using targets that differ significantly in complexity in future studies. The possibility of targeting different levels of complexity with different participants, or not collecting a baseline for a second target group until treatment for the first target group has been completed, could be explored. We would also suggest increasing the number of treatment sessions since the accuracy did increase for 7 to 11 word sentences even though treatment data was only collected for five sessions.

In conclusion, the current study demonstrates that the combination of reducing the frequency of delayed feedback (knowledge of result) and random practice with 25 trials enhances motor learning in an adolescent with CAS at the word level and, to some degree, at the sentence level. Although some limitations exist, this study contributes to the scanty research that has been published on motor learning theory-based approaches for adolescents with CAS and supports clinicians seeking to develop effective treatment approaches for those populations.

APPENDIX I

Treatment Protocol

Five minute pre-practice (overview of the purpose of the treatment, correct response, and what the feedback used means)

Step 1. The clinician and patient produce the target utterance simultaneously. If the production is wrong, they continue to say it together.

A. Patient attempts utterance without assistance. (No feedback)

B. Patient produces utterance 5 times with 4-second pause between each attempt.

C. After 3 attempts, clinician repeats/models the utterance, waits 4 sec., and then provides KR.

Step 2. The clinician produces the utterance, waits 4 seconds and the utterance is elicited from a written stimulus card in random order.

A. Patient attempts utterance without assistance. (No feedback).

B. Patient produces utterance 5 times with 4-second pause between each attempt.

C. After 3 attempts, clinician repeats utterance, waits 4 sec., and provides KR.

Step 3. The utterance is elicited from a written stimulus card in random order.

A. Patient attempts utterance without assistance. (No feedback).

B. Patient produces utterance 5 times with 4-second pause between each attempt.

C. After 3 attempts, clinician repeats utterance, waits 4 sec., and provides KR.

(Step 3 continues for a block of 5 stimulus items. A short break (2-min) may take place after Step 3.) Repeat steps 1-3 with another block of five stimulus items.

Step 4. The utterances are randomly elicited from written stimulus card (20 utterances).

A. Patient attempts utterance without assistance. (No feedback).

B. Patient produces utterance 5 times with 4-second pause between each attempt.

C. After 3 attempts, clinician repeats utterance, waits 4 sec., and provides KR.

Step 5. Repeat the step 4.

C. Patient attempts utterance without assistance. (No feedback).

D. Patient produces utterance 5 times with 4-second pause between each attempt.

C. After 3 attempts, clinician repeats utterance, waits 4 sec., and provides KR.

APPENDIX II

11 Point Multidimensional Scoring Scale

Rating scores	Description
11	Accurate (within two seconds)
10	Delay, searching, groping, facial grimace
9	Inefficient, poor prosody, distortion, drawn out, grimace
8	Delayed (2+ seconds), inefficient, poor prosody, facial grimace
7	Addition or deletion of a sound, use of a starter phrase
6	Repeat, asks for repetition
5	Self-correction
4	Incomplete, omits part of word or phrase that changes meaning
3	Error (any articulation error)
2	Error (articulation) plus a delay (2+ seconds)
1	Perseveration (produces previous response)

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Received on 10-04-2015 Accepted on 16-07-2015 Published on 17-09-2015

DOI: http://dx.doi.org/10.12970/2311-1917.2015.03.02.3