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Perceptual and Articulatory Changes in Speech Production Following PROMPT Treatment

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Abstract

PROMPT (Prompts for Restructuring Oral Muscular Phonetic Targets) is a treatment approach that is widely used to improve sound production in children with speech impairments. This approach uses tactile cues to support and shape movements of the oral articulators in order to improve the production of individual sounds, syllables, words, and eventually connected speech. The underlying assumption is that tactile cuing will facilitate changes in articulator movements. This investigation examined articulator movement as well as the accuracy of speech production, before, during, and after a period of PROMPT treatment in a child with severe articulation impairment. A typically developing child was followed longitudinally as a control. The following research questions were addressed: (1) Does speech sound accuracy improve over an eight-week course of PROMPT treatment? (2) Does articulator movement (duration, displacement, velocity) change over an eight-week course of PROMPT treatment? The results revealed increased articulation accuracy and decreased movement duration, displacement, and velocity over the course of PROMPT treatment in the child with the articulation impairment. By the last treatment session, kinematic findings were most similar to those seen in the control. These results suggest that PROMPT facilitated changes in articulatory control in a single participant.

Keywords

speech impairment; intervention; articulator movement; development

INTRODUCTION

PROMPT (Prompts for Restructuring Oral Muscular Phonetic Targets) is a treatment approach that facilitates production of sequenced speech movements in speech-impaired children (Chumpelik [Hayden], 1984). This treatment is a multidimensional approach based on dynamic systems theory and consistent with neuronal group selection theory (Sporns & Edelman, 1993) and Guenther's neural model of speech production (Guenther, 2006; Tourville, Reilly, & Guenther, 2008). In PROMPT, multiple movement parameters and coordinative actions are associated with each sound (e.g., voicing, jaw height, facial-labial contraction, lingual independence). It is hypothesized that tactile input provides information

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to the speaker about where movements begin, how they feel, and how they should be produced. Thus, the clinician provides systematic tactile-kinesthetic input to inhibit or facilitate movement of the articulators during sound, word, or phrase production. The underlying premise is that while trying to learn new motor speech movements, tactual input reinforces changes in sensory mappings, which ultimately improves motor planning and execution (Hayden, 1994, 2004; Hayden, Eigen, Walker, & Olsen, 2010). While there are several reports showing the effectiveness of PROMPT (Rogers et al., 2006; Square, Goshulak, Bose, & Hayden, 2000; Ward, Leitao, & Strauss, 2009), changes in speech motor control as a result of this treatment approach have not been widely studied. This investigation examines articulator movement and the accuracy of speech production, before, during, and after a period of PROMPT treatment. The following research questions were addressed: (1) Does speech sound accuracy improve over a period of PROMPT treatment? (2) Does articulator movement duration, displacement, and velocity change over a period of PROMPT treatment?

METHOD

Participants

Two, 3-year-old males (M = 3 years, 7 months) participated in the study. One child had a speech disorder (SD) and the other served as a control. Both children passed a hearing screening and demonstrated age-appropriate cognition and receptive language as measured through the *Columbia Mental Maturity Scale* (CMMS) (Burgemeister, Blum, & Lorge, 1972) and the *Test of Early Language Development* (TELD-3) (Hresko, Reid, & Hammill, 2007). A 100-word conversational speech sample was obtained from each child. Pre- and post-performance measures were collected using the *Diagnostic Evaluation of Articulation and Phonology (DEAP)* (Dodd, Hua, Crosbie, Holm, & Ozanne, 2006) and the *Verbal Motor Production Assessment for Children* (*VMPAC*, Hayden & Square, 1999) as a measure of oral motor skills. The control participant displayed age-appropriate speech, language, and oral motor skills, and the child with SD was diagnosed with a severe articulation impairment. Prior to treatment, the child with SD displayed severe deficits on the DEAP, with an overall scaled score of 2. For most areas on the VMPAC, his scores feel around the 5th percentile; only the Global Motor Control and Speech Characteristic Areas were age appropriate. Articulation was characterized by reduced phoneme inventories, omissions, substitutions, distortions, and the use of simple syllable/word shapes. The System Analysis Observation (Hayden, 2001) was used to analyze the participant’s motor control during speech production. Deficits with jaw control were observed, including inappropriate degrees of freedom (e.g., excessive jaw movement and sliding during volitional speech), which often resulted in the omission of final movements in consonant vowel consonant (CVC) sequences. In addition, minimal to no upper lip movement in bilabial productions was observed and rounded productions (e.g., “boo”) were absent. Finally, limited to no independence of the tongue from the jaw was observed, and productions requiring anterior tongue movements (e.g., /n/, /t/, or /d/) were omitted.

Instrumentation and Procedure

A motion capture system (Vicon 460, Vicon Motion Systems, 2001) was used to track articulator movement in three dimensions. The system tracked eight reflective markers (3 mm in diameter) at a sampling rate of 120 frames per second. The jaw marker was placed superior to the mental protuberance and the lip markers on the midline of the vermillion border of upper and lower lips. Nose and forehead markers were used to account for head movement, as the jaw and lip markers were subtracted from these points. Audio recordings were made using a digital minidisc recorder (M-Audio, MicroTrack 2496) and lapel microphone.

The child with SD received 16 PROMPT treatment sessions (each 45 minutes) over the course of eight weeks, while he visited New York with his family during the summer. Treatment was provided by the third author, an ASHA (American Speech-Language-Hearing Association)-certified speech language pathologist with PROMPT Certification. Accuracy of 25 trained words was examined weekly. In addition, 40 untrained probe words were collected three times PRE treatment (before treatment began), each week during treatment, and once at a POST session (five-month follow-up) for a total of 12 untrained probe word data points. Delay of the POST session was due to travel difficulty, as the child lived out of state. The child did not receive PROMPT during this time. Kinematic data were collected biweekly for a total of six sessions (PRE treatment, Weeks 2, 4, 6, 8, and POST treatment). The stimuli included six untrained words in the *Mandibular* (i.e., "mop" and "pup"), *Labial-Facial* (i.e., "beep" and "moon"), and *Lingual* (i.e., "sun" and "dot") categories. For the control participant, kinematic data were collected biweekly (total of six sessions) and 40 untrained probes were obtained in one session.

Initial treatment priorities targeted ten words in the *Mandibular* stage (e.g., words that use low vowels and jaw movement to drive bilabial productions, such as "up" and "mom") and ten words in the *Labial-Facial* stage (e.g., words that use rounded or retracted labial facial movements and restricted jaw movements, such as "you" and "one"); in the last three sessions, five words in the *Lingual* stage (e.g., words that require stable, graded jaw control, a closing phase in a CVC and independent anterior tongue control, such as "done" and "not") were added as targets. Treatment sessions consisted of a combination of mass practice or motor phoneme warm-up drills before activities and distributed practice during varied play routines (e.g., constructive, symbolic, social).

Analyses

Transcription and Visual Analyses—Three analyses were performed by listeners blind to the assessment session. Two listeners transcribed and calculated Percentage Consonants Correct (PCC) (Shriberg & Kwiatkowski, 1982) and Percentage Vowels Correct (PVC) (Shriberg, 1983) from audio-recordings of tokens produced during kinematic data collection sessions. Three different scorers transcribed and calculated PCC/PVC and completed a visual analysis of the 40 untrained probe words. The visual analysis used a three-point scale (0 = "no appropriate movements"; 3 = "all appropriate movements") to examine accuracy of mandibular, labial-facial, and lingual control across three dimensions (i.e., movement symmetry, timing of movements, and transition between movements). Two additional listeners transcribed and scored all trained words as either correct (1) or incorrect (0) based on both auditory perceptual and visual motor accuracy. Reliability testing was performed separately on the visual and transcription analyses on 25% of tokens. Agreement between scorers was 90% on the visual analysis and 92% on the transcription analysis.

Kinematic Analysis—Kinematic data were analyzed using Matlab Pro 7.2 (Matlab, 2007). The first eight trials (correct and incorrect productions) that did not involve extraneous movements, atypical vocalizations (e.g., crying), or missing reflective markers were included in the analysis. Measures of duration were based on movement in the jaw velocity trajectory. Oral opening duration was measured as the time between zero crossing points before and after the maximum velocity for the vowel. Oral closing duration was calculated as the time between the zero crossing points before and after the maximum velocity for the consonant, Jaw, lower lip and upper lip displacement, and velocity were examined. Opening displacement was calculated as the peak to trough displacement into the vowel, and closing displacement was calculated as the trough to peak displacement into the final consonant. Maximum opening and closing velocities were used as measures of movement velocity.

Statistical Analysis—Paired samples t-tests were performed to test comparisons between the PRE session and Week 8 (last treatment session) in the child with SD. Comparisons were not made with the POST session, given the lapse in time. One comparison was made for each kinematic parameter (opening duration, closing duration, opening displacement, closing displacement, opening velocity, closing velocity) for each articulator (jaw, lower lip and upper lip), yielding 18 comparisons which adjusted the alpha level to 0.002. Interval estimation was used to compare the child with SD to the control participant. This method uses an interval as an estimator rather than a single value (McCall, 1994). A mean and 95% confidence interval was calculated from the control data across sessions for each kinematic parameter, establishing an upper and lower limit. Comparisons were then made between the child with SD's and the control participant's mean performance.

RESULTS

Perceptual changes

Consonant and vowel accuracy in untrained probe words improved across treatment sessions (Table 1). The most notable consonant changes were seen in the *Mandibular* and *Labial-Facial* stages. In the untrained kinematic tokens, consonant accuracy increased from the PRE session to Week 8, with the largest changes seen in the *Mandibular* and *Labial-Facial* categories. Vowel accuracy varied and was high at PRE in some tokens (i.e., "pup") and decreased in others across sessions as consonant accuracy improved (i.e., "mop"). Visual scoring revealed steady increases in articulatory precision across trained and untrained words.

Movement Kinematics

Figure 1 shows means and standard deviations for jaw duration, displacement, and velocity for the child with SD across sessions, as well as the mean (across sessions) and 95% confidence interval for the control participant. Jaw duration for opening and closing decreased across sessions in the child with SD and tended to be smallest at Week 8, the last treatment session. Significant decreases in duration were seen for opening in "mop" ($t(7) = 10.99$, $p < .001$) and "sun" ($t(7) = 5.01$, $p = .001$), as well as for closing associated with the final consonant in "mop" ($t(7) = 4.3$, $p = .003$) and "dot" ($t(7) = 4.92$, $p = .001$). There was little change in duration in the control participant across sessions. Opening and closing duration in the child with SD fell above the control's 95% confidence interval at PRE and within this interval at Week 8. Duration increased into the POST session.

Jaw opening and closing displacement decreased in all tokens from the PRE session to Week 8. While decreases were not steady across sessions, displacement was smallest at Week 8. Significant decreases from PRE to Week 8 were seen in jaw opening displacement in "mop" ($t(7) = 4.98$, $p = .002$) and "sun" ($t(7) = 5.83$, $p < .001$), as well as in jaw closing displacement associated with the final consonant in "dot" ($t(7) = 7.94$, $p < .001$). At the PRE session, opening and closing displacement was greater than the control's 95% confidence interval. Displacement was within or below the 95% confidence interval by Week 8 for all tokens with the exception of "moon" and "beep." Lower and upper lip displacement decreased across sessions; however, these changes only reached significance in upper lip opening in "mop" ($t(7) = 10.6$, $p < .001$). Comparisons with the control showed that lower and upper lip displacement was often greater than the control's 95% interval at the PRE session, decreased across sessions, but remained greater than the control at Week 8. Overall, decreases in jaw and lip displacement were not maintained at the POST session.

Across sessions, movement velocity decreased in the child with SD, while small differences were seen in the control participant. Jaw, lower lip, and upper lip velocity were smallest at

Week 8 in the child with SD. Significant decreases in jaw opening velocity were seen in “mop” ($t(7) = 4.79$, $p = .002$), “sun” ($t(7) = 5.03$, $p = .001$), and “dot” ($t(7) = 5.19$, $p = .001$). Changes in “mop” were maintained at the POST session. At the PRE session, all tokens with the exception of “beep” fell above the control’s 95% confidence interval. At Week 8, most tokens were within the control’s 95% confidence interval. Although opening and closing lower lip velocities decreased, these findings did not reach statistical significance. In the upper lip, significant decreases were seen from the PRE session to Week 8 in opening velocity in “mop” ($t(7) = 8.03$, $p < .001$) and closing velocity in “sun” ($t(7) = 7.1$, $p < .001$). Lower and upper lip velocities tended to be greater than the control’s 95% confidence interval at the PRE session but within the range at Week 8. Exceptions to this were seen in “beep” and “moon” where lip velocities were within the control participant’s 95% confidence interval.

DISCUSSION

The results of this study revealed changes in oral articulator movement and consonant/vowel accuracy in the production of both trained and untrained words across a short period of PROMPT treatment. At the onset of treatment, excessive jaw excursion and fixed lip retraction were seen in the child with SD. This limited his ability to vary lip movements and accurately grade jaw movements to achieve phonetic targets. Consistent with these observations, articulator movements were longer in duration and greater in displacement and velocity in the child with SD compared with the typically developing control.

Consonant and vowel accuracy increased, while movement duration, displacement, and velocity decreased across treatment sessions in the child with SD. In contrast, the control participant produced phonemes with at least 90% accuracy and small differences in articulator movement across sessions. The most notable changes in the child with SD occurred at Week 8, the last treatment session. While decreases in both lip and jaw movement were evident throughout the data, significant changes were mainly seen in the jaw. Emphasis on jaw movement control during treatment contributed to improved oral closure for bilabial phonemes, as well as for oral opening for /a/ and /^/. While the child with SD did not initially display the well-established jaw movement patterns that are described in young children (Green, Moore, Higashikawa, & Steeve, 2000; Green, Moore, & Reilly, 2002; Grigos, 2009; Grigos, Saxman, & Gordon, 2005; MacNeilage & Davis, 1993, 2000), he developed more refined jaw movements over the short time period under study. Tactual input provided through PROMPT appeared to have influenced mandibular control, thereby facilitating improved phoneme productions. The articulator movement changes seen across this treatment period support the notion that tactile input reinforces changes in speech motor control (Hayden, 1994, 2004; Hayden et al., 2010). Post-session results for consonant/vowel accuracy and visual precision for trained and untrained words revealed that most gains were maintained, providing evidence of generalization. There was some carryover involving lingual targets even though they were only focused upon during the last three treatment sessions. Kinematic data from the POST session showed poorer maintenance of skills, but some results were still above baseline levels. While finely graded control of the jaw and lip movements was not maintained from Week 8 to the POST session, consonant and vowel accuracy were preserved across many tokens.

Changes in articulator movement were influenced by the phonetic structure of the tokens. Difficulty with jaw control was particularly evident in low vowel productions. While significant decreases in jaw movement were seen in oral opening for /a/ and /^/, vowel accuracy varied across sessions. Closing duration for “mop” and displacement in “dot” decreased into Week 8; however, the vowel in those tokens was often substituted with /^/. It appeared as if using independent lip and/or tongue movements with a more reduced jaw range resulted in a substitution of this higher vowel. It is possible the child with SD was beginning to reorganize his speech subsystems (e.g., mandibular and labial-facial control) but had not yet consolidated these interactions by the last session. Phonemes involving lip retraction and protrusion (e.g., "beep" and "moon") were produced accurately by Week 8, although lip movements continued to display greater displacement and velocity as compared to the control. The exaggerated movements of the child with SD suggest that he was having difficulty maintaining jaw control while using his lips independently. Taken together, our findings indicate that PROMPT facilitated improved phonemic accuracy and more refined articulatory control in this child. Further research is warranted to compare the efficacy of PROMPT to other treatment approaches on a larger group of speech-disordered children.

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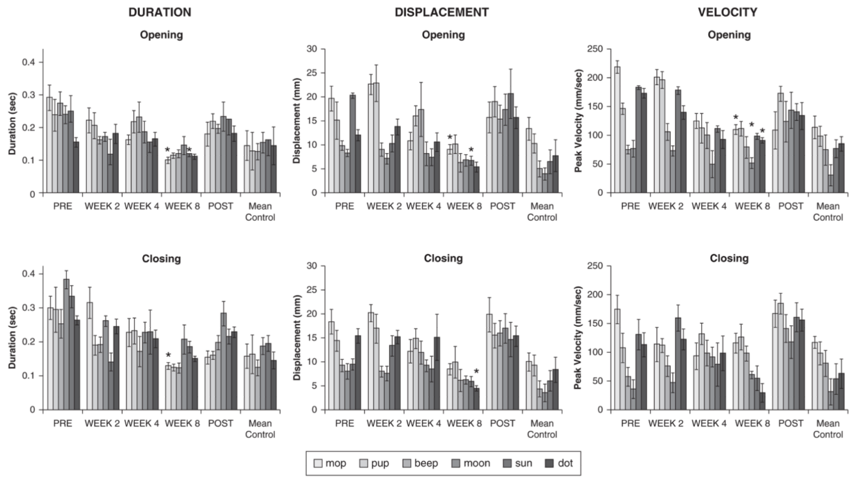

Figure 1.

Mean and Standard Deviations of Jaw Duration, Displacement, and Velocity in the Child with SD in the PRE Session, Weeks, 2, 4, and 8 of Treatment, and the POST Session. The Mean (Across Sessions) and a 95% Confidence Interval are shown for the Control. The Asterisk (*) indicates a Significant Difference from PRE in the Child with SD

TABLE 1

Visual Accuracy, Percent Consonant Correct (PCC) and Percent Vowel Correct (PVC) for Trained and Untrained Words.

	Visual Accuracy: Untrained Probe Words				Visual Accuracy: Trained Words		
	Mandibular	Labial/Facial	Lingual		Mandibular	Labial/Facial	Lingual
PRE	23	1	16	PRE	10	0	0
Week 2	30	53	23	Week 2	20	10	0
Week 4	56	63	23	Week 4	40	43	0
Week 6	80	70	23	Week 6	66	50	50
Week 8	80	63	30	Week 8	92	90	100
POST	83	60	57	POST	64	77	89
Control	100	100	93				
	PCC: Untrained Probe Words				PVC: Untrained Probe Words		
	Mandibular	Labial/Facial	Lingual		Mandibular	Labial/Facial	Lingual
PRE	36	13	22	PRE	55	80	80
Week 2	57	44	26	Week 2	82	60	90
Week 4	42	56	34	Week 4	64	80	80
Week 6	78	61	34	Week 6	91	70	100
Week 8	86	75	47	Week 8	82	80	80
POST	78	63	61	POST	91	80	90
Control	93	100	96	Control	100	100	100
	PCC: Untrained Kinematic Tokens				PVC: Untrained Kinematic Tokens		
	Mandibular mop/pup	Labial/Facial beep/moon	Lingual sun/dot		Mandibular mop/pup	Labial/Facial beep/moon	Lingual sun/dot
PRE	50/25	50/50	75/50	PRE	100/38	100/75	100/50
Week 2	44/50	56/50	69/50	Week 2	100/50	88/100	50/38
Week 4	50/62	56/50	81/50	Week 4	88/50	88/100	75/50
Week 8	94/94	94/56	88/100	Week 8	38/87	100/100	75/25
POST	81/94	94/50	62/100	POST	87/13	88/100	88/100
Mean	99/98	95/97	100/93	Mean	95/90	99/100	98/95
Control				Control			