Curr Dev Disord Rep. Author manuscript; available in PMC 2015 September 01.

Published in final edited form as:

Curr Dev Disord Rep. 2014 September ; 1(3): 197–206. doi:10.1007/s40474-014-0016-4.

Motor-based intervention protocols in treatment of childhood apraxia of speech (CAS)

Edwin Maas, Ph.D.[1], **Christina Gildersleeve-Neumann, Ph.D., CCC-SLP**[2], **Kathy J. Jakielski, Ph.D., CCC-SLP**[3], and **Ruth Stoeckel, Ph.D., CCC-SLP**[4]

Edwin Maas: emaas@email.arizona.edu; Christina Gildersleeve-Neumann: cegn@pdx.edu; Kathy J. Jakielski: kathyjakielski@augustana.edu; Ruth Stoeckel: restoeckel@gmail.com

[1]Department of Speech, Language, and Hearing Sciences, University of Arizona, 1131 East Second Street, PO Box 210071, Tucson, AZ 85721-0071, Phone: (520) 626-6460, Fax: (520) 621-9901

[2]Speech and Hearing Sciences Department, Portland State University, Portland, OR 97207-0751, Phone: (503) 725-3230, Fax: (503) 725-9171

[3]Communication Sciences and Disorders, Augustana College, 639 38th Street, Rock Island, IL 61201, Phone: (309) 794-7386, Fax: (309) 794-3497

[4]Department of Neurology, Mayo Clinic, 200 1st St SW, Rochester, MN 55905, Phone: (507) 284-5834, Fax: (507) 538-6012

Abstract

This paper reviews current trends in treatment for childhood apraxia of speech (CAS), with a particular emphasis on motor-based intervention protocols. The paper first briefly discusses how CAS fits into the typology of speech sound disorders, followed by a discussion of the potential relevance of principles derived from the motor learning literature for CAS treatment. Next, different motor-based treatment protocols are reviewed, along with their evidence base. The paper concludes with a summary and discussion of future research needs.

INTRODUCTION

Speech sound disorders (SSD) historically have been classified using descriptive linguistic typologies, which by their nature ignore causation. Shriberg's Speech Disorders Classification System (SDCS) [1–3] was the first attempt at categorizing SSD by etiology. Shriberg [1,2] proposed that a clinical typology based on the pathogenesis of SSD could focus attention on differences in causal factors among the various subtypes of SSD, as well

Conflict of Interest

Edwin Maas received grants from National Institute on Deafness and Other Communication Disorders, during the conduct of the study; personal fees from Childhood Apraxia of Speech Association of North America, personal fees from SpeechPathology.com.
Christina Gildersleeve-Neumann declares that she has no conflict of interest.
Kathy J. Jakielski declares that she has no conflict of interest.
Ruth Stoeckel received personal fees from Childhood Apraxia of Speech Association of North America.

Compliance with Ethics Guidelines

Human and Animal Rights and Informed Consent

This article does not contain any studies with human or animal subjects performed by any of the authors.

as differences in speech onsets, normalization trajectories, and factors that contribute to persistent SSD. Over 25 years ago, Pannbacker [4] recognized the need to identify SSD subtypes and develop subtype-specific interventions; the SDCS provides a foundation to address that need.

The most recent version of the SDCS [5••] proposes three distinct SSD classifications: Speech Delay, Speech Errors, and Motor Speech Disorder (MSD). The classification of MSD includes three subtypes: dysarthria, apraxia of speech, and MSD not otherwise specified; dysarthria is associated with speech motor execution deficits, whereas childhood apraxia of speech (CAS) is associated with speech motor preparation (i.e., planning/ programming) deficits. Speech motor preparation deficits are unique to CAS and differentiate it from the other SSD classifications, as well as from the other MSD subtypes. By current consensus [6], the signature symptoms of CAS include inconsistent errors on vowels and consonants, difficulties with coarticulation, and prosodic abnormalities. Individuals with CAS also may demonstrate difficulties with forming, storing, and retrieving representations of auditory/perceptual information to a lesser extent [5••]. In addition, CAS occurs in a variety of etiological contexts, including neurogenetic, neurological, and idiopathic, and its symptomatology may vary based on context [5••]. Of children diagnosed with SSD, an estimated 3–5% exhibit the CAS subtype [2]. In this article, we discuss interventions for CAS specifically, with an emphasis on motor-based interventions, and will not discuss approaches for which the primary focus is not speech production [7]. First, we review concepts relevant to speech motor control and learning; in particular, we briefly note some practice conditions that have been found to facilitate motor learning and review the extent to which such practice conditions may also facilitate *speech* motor learning in children with CAS.

SPEECH MOTOR CONTROL AND LEARNING

Speech production is a complex motor skill that requires coordination across many different muscle groups with extraordinary spatiotemporal demands. It is not surprising that some children have difficulty acquiring adequate speech. Children with CAS often make little or slow progress with standard treatment and may require more extensive periods of treatment [8,9]. Given the challenges in many clinical settings (e.g., high caseloads, limited third-party reimbursements), maximizing use of limited resources is imperative.

A promising resource for optimizing treatment is the motor skill learning literature. A number of conditions have been found to facilitate learning (retention and transfer) of motor skills, compared to other conditions [10]. These relatively predictable advantages of some conditions over others (e.g., more practice facilitates learning compared to less practice) are sometimes referred to as *motor learning principles* [11,12]. In the last 15 years, incorporation of motor learning principles into treatment for CAS has been recommended [12–18]. Several published treatment studies have implemented some of these principles [12,19–20], but few studies have systematically compared practice conditions in CAS treatment [14••,21–22•]. In this section, we briefly review important concepts and trends in extending this research paradigm to examining its relevance for enhancing speech motor learning. We focus on the behavioral motor learning literature that has provided concrete and applicable examples of how certain practice conditions can enhance learning of a range of motor skills. Much, though by no means all, of this literature has been inspired by the Schema Theory of motor control and learning [10,23], which has led to a number of practical predictions about how to optimize motor learning. Of course, other theoretical frameworks exist that may account for some of the findings in the literature, such as the Dynamical Systems framework [24]. To date however, this latter framework has not been widely used to generate a systematic program of research on the practical factors that clinicians might incorporate to optimize motor learning; most learning research within this framework has focused on the coordination dynamics of reiterant, rhythmic tasks such as repeatedly producing the same movement pattern [24–27]. However, our present focus is not on discussing different theoretical frameworks but rather on the empirical findings relevant to practical and clinically usable factors that may optimize motor learning.

The motor learning literature distinguishes between performance during practice and learning [10,11]. True learning is evidenced by enhanced performance on tests of retention (maintenance) and/or transfer (generalization), both indicating sustained changes in the capability of the motor system to perform movement tasks. Performance changes seen during practice may reflect processes that result in true learning but also those that are only temporary in nature (e.g., changes in motivation, fatigue). This distinction is important because factors that enhance learning (retention and transfer) are not necessarily the same factors that enhance practice performance. For example, providing feedback after every trial enhances performance during practice compared to providing feedback on only some trials, but this pattern is reversed for retention and transfer, where less feedback results in better performance [28,29].

There is a current trend to extend motor learning principles to speech production and its disorders. In addition to reviews [11,30] and studies that incorporate (but do not manipulate) motor learning principles [12,19,31,32], a growing number of studies specifically compare different conditions of practice and feedback in a variety of populations. Studies with typical speakers have examined *practice schedule* (random vs. blocked schedule) [33–35], *practice amount* (small vs. large number of trials) [36], *practice variability* (constant vs. variable targets) [33], *feedback frequency* [33,36–38], *feedback control* (instructor/therapist-controlled vs. self-controlled) [39], and *attentional focus* (external vs. internal) [40]. Although not all studies report significant differences [39], findings are generally consistent with the motor learning literature.

For individuals with speech/voice impairments, studies have examined *practice amount* [14••], *practice schedule* [22•,41,42], *practice variability* [43], *practice distribution* (massed vs. distributed) [42,44,45], *feedback type* (verbal knowledge of results vs. biofeedback knowledge of performance) [46], *feedback frequency* [21,47–51], *feedback timing* (immediate vs. delayed) [48] and *attentional focus* [52]. Although some studies reported findings consistent with the motor learning literature [14••,41,47], others failed to find clear and consistent differences between conditions [42,43,45,51,52], or reported opposite effects for some participants [22•,44]. It is likely that differences in tasks, measures, and populations contribute to this mixed pattern. Further research is needed to determine the parameters that predict optimal conditions for a given task and individual.

With respect to CAS specifically, only three published studies have examined conditions of practice and feedback directly [14••,21,22•]. All three used a single-case experimental (alternating treatments) design. Edeal and Gildersleeve-Neumann [14••] examined practice amount for 2 children with CAS in an integral stimulation treatment approach. They selected two sets of speech targets for each child and randomly assigned these sets to a high-frequency (100–150 trials per session) or a moderate-frequency condition (30–40 trials per session). Both children demonstrated greater retention and transfer for high-frequency targets than for moderate-frequency targets, consistent with findings from the motor learning literature [53,54].

Maas and Farinella [22•] compared random versus blocked practice in 4 children with CAS using a modified Dynamic Temporal and Tactile Cueing (DTTC) treatment [12]. Targets involved small sets of words and were individualized for each child. There were two treatment phases to provide replication, and effects were combined across phases. Findings indicated greater retention for random practice targets in both phases for one child, but 2 children showed opposite effects across phases, with a small net advantage for blocked practice. The fourth child did not show improvement in either condition or phase, and generalization was negligible for all children. These findings are less clear-cut than those in the motor learning literature [54,55] and the adult AOS literature [41].

Maas et al. [21] compared high versus reduced frequency of verbal feedback in 4 children with CAS. While 2 children showed the expected advantage of reduced feedback frequency on retention, there was a slight advantage of high feedback frequency for a third child, whose CAS symptoms were more severe. The fourth child showed no gains in either condition. Thus, findings were again mixed, indicating that more research is needed specifically investigating these factors with populations of interest (e.g., various types of speech disorders) to understand when and for whom certain practice conditions are beneficial. One possibility is that high feedback frequency enhances learning for children who are younger [56] or whose CAS symptoms are more severe, whereas older children or those with less severe CAS symptoms benefit from reduced feedback frequency.

In sum, while there is some convergence with the nonspeech motor learning literature in terms of effects of motor learning principles for typical speakers and for some SSDs, including CAS, there are also a number of mixed, null, or opposite findings. Some of these differences may be related to the complexity of speech motor control, because learning of complex movements may not be facilitated by the same practice conditions as simple movements [57,58]. Moreover, only a small number of motor learning principles have as yet been studied in CAS treatment. For example, practice distribution [59] has not yet been studied in this population, despite its potential clinical relevance. Practice distribution may also explain some differences between studies. For example, Strand and colleagues [12,20] observed large effects in their studies providing DTTC twice per day, five times per week, over 6 weeks, whereas Maas and colleagues [21,22•] found relatively modest effects when providing modified DTTC treatment three times per week over 8 weeks (overall treatment ~30 vs. ~24 hours). Thus, practice distribution is a potentially powerful and relevant variable [44] that has not been studied directly in CAS treatment. Nevertheless, even if conditions of practice and feedback act differently in the speech domain or for some populations, the literature on motor learning principles is a rich source of hypotheses for future studies and offers a structured research paradigm to explore such effects and understand how to optimize treatment outcomes for children with CAS.

MOTOR-BASED TREATMENT APPROACHES

Target Selection

One of the first decisions that must be made in the clinical management of a child with CAS is deciding which type of targets will be taught. Within the therapy session is where children engage in guided motor practice, and that practice is what results in increased performance, and eventually in motor learning. Therefore, *what* children practice, in addition to *how* children practice, deserves careful deliberation. The type of targets selected should be decided after considering many factors, including a child's age, severity of CAS, language and cognitive status, concomitant disorders, motivation, and prognosis. The possible types of targets are numerous and diverse, and include isolated speech movements, speech sounds, syllables, phonetically-modified words, real words, nonsense words, and phrases/sentences.

Shriberg and colleagues [60] suggested that the core symptoms used to differentially diagnose CAS from other SSDs should be related directly to the speech motor preparation deficits associated with CAS (e.g., abnormal stress marking, inconsistent consonant errors), as opposed to being a more indirect consequence of such deficits (e.g., reduced intelligibility). Applying similar reasoning to target selection, the targets should address at least one core feature of CAS that has been attributed to speech motor preparation deficits.

Because there are multiple types of targets we might select for therapy, motor learning principles can inform decision-making. Motor learning principles related to pre-practice conditions may be most applicable to target selection. Two primary functions of pre-practice include motivating the client and ascertaining that the client is stimulable for the task [10,61]. To increase motivation in therapy, having the child help select specific treatment targets can be beneficial, as can selecting words/phrases with functional communicative relevance to the individual [12,14••,20]. Stimulability may facilitate motivation in that selecting targets that are within the child's capacity under optimal conditions (e.g., with auditory, verbal, and tactile cueing) is likely to reduce the failure rate during practice. As a child progresses in treatment, additional, more challenging targets can be incorporated by incrementally building on the success of previously-learned movement patterns.

Although different CAS-specific interventions (reviewed below) incorporate motor learning principles [12,20–22•,62••–64], each approach may focus on different targets. For example, in DTTC [12,20], functional words and phrases are targeted primarily, although nothing in the approach precludes targeting other speech elements (e.g., syllables, words). In Rapid Syllable Transition (ReST) [62••], strings of nonsense syllables are targeted, while in the Nuffield Dyspraxia Programme (NDP3) [63,64], intervention begins by targeting consonants and vowels in isolation.

Another consideration is the principle of task specificity, which states that the most effective practice closely mimics the target skill [10,65]; therefore, selecting real words might be appropriate because when learned, the child could use these exact words in different contexts. However, selecting nonword targets might also be appropriate, if one assumes that CAS is a disorder of speech sequencing. That is, if the targeted underlying skill is sequencing and transitioning between sounds and syllables, then practicing a range of different sequences without meaning might allow a child to focus on and improve this underlying skill and generalize to novel contexts, including real words. Of course, success using nonword targets depends on a child’s ability to generalize improved skills learned in the context of nonword forms to real words, and may be more appropriate for older children and/or children with relatively mild impairments; for younger children and/or those with more severe CAS the use of functionally relevant real words may be more appropriate as this would likely facilitate motivation and practice outside the clinic [19]. Even though children with CAS typically possess a very limited ability to generalize speech movements across sounds, syllables, and words [20–22•], research on ReST is documenting generalization from nonword targets [19]. However, the principle of task specificity suggests that the movements to be taught and practiced should be *speech* movements, in contrast to oral movements such as lip spreads and lateral movements of the tongue in the absence of speech [11,66].

A final consideration relates to target complexity. It is difficult to determine and measure speech complexity [11] and there are multiple interpretations of it [40,67,68]; however, clinical decisions regarding basic versus complex speech targets typically are made by considering production aspects such as place and manner features and phonotactic structure. Three CAS-specific intervention approaches [12,20,62••–64] employ a “bottom-up” approach – establishing simpler speech movement patterns before progressing to more complex ones. There are also “top-down” intervention approaches for children with phonological impairment [69,70], although none have been designed for or tested with children with MSD.

Integral Stimulation Approaches

ASHA’s Technical Report on CAS [6] recommends treatment for CAS be frequent, intensive, individualized, and naturalistic. Although a specific treatment approach is not endorsed, the use of motor learning principles is recommended [6]. Unfortunately, evidence supporting effective treatment approaches for children with CAS is limited: most treatment research has not been conducted in controlled experimental conditions. Nevertheless, there are promising treatment approaches for CAS that incorporate motor learning principles. Currently, integral stimulation approaches, including DTTC [12], have the most research supporting their effectiveness in children with CAS, with multiple experimental single-case experimental design studies demonstrating improvement in speech production in individual children [12,14••,20–22•]. Integral stimulation refers to a hierarchical intervention approach originally developed for apraxia of speech in adults [71] and involves imitation (“watch me, listen, and do what I do”) and motor learning principles. In the past 10 years, research using modified integral stimulation approaches has been conducted with children.

DTTC [12], an example of an integral stimulation approach, combines motor learning principles, cues, and modeling to encourage speech target production [20]. The clinician facilitates speech through imitation. The child's articulation is shaped through multimodal cueing techniques (including tactile, visual, auditory, and proprioceptive cues) to promote accurate movement gestures. Cues are individualized dependent on the child's response and motivation [20,71]. Cues can vary trial-to-trial to facilitate motor planning and programming necessary for the child's speech output. The approach includes advancing from easier speech targets to more challenging sounds or word shapes, using a variety of cues to shape movement gestures and gradually fading these cues, varying the length of stimuli, and varying the time from presentation of the model to the child's response. Initially, the clinician encourages the child to imitate a slower speech rate to increase motor planning time and facilitate awareness of tactile and proprioceptive cues by allowing the child more time to process such cues. As the child's motor planning improves, rate is slowly increased to conversational rates.

While DTTC is hierarchical, in that supports are lessened as the child's independent speech movements increase in accuracy, successful application of DTTC requires a rapid and fluid increase and decrease of supports based on each individual's needs. Clinician supports often change from trial-to-trial as the child's production accuracy varies. Repetitive intensive drill of functional vocabulary is a key aspect and is intended to increase generalization of motor patterns for speech productions to functional communicative settings. DTTC was developed in particular for children who are younger and/or whose CAS is severe (including those who are essentially nonverbal) [12,20].

DTTC effectiveness for CAS has been demonstrated in multiple single-case experimental design studies [12,20,72]. More recent studies have utilized DTTC to explore the efficiency of specific motor learning principles in treating CAS [14••,21,22•], while providing further validation of the effectiveness of DTTC.

In the first published application of DTTC, Strand and Debertine [20] utilized a multiple baselines across behaviors design with a 5-year-old girl with severe CAS. Therapy was conducted 4 days a week in intensive 30-minute blocks for 33 sessions. Speech accuracy (as judged perceptually by the clinician) of targeted functional phrases increased; no generalization to untrained targets was demonstrated. Strand and colleagues [12] utilized DTTC to improve speech production in four 5- to 6-year-old boys with severe CAS. Treatment was conducted twice a day, 5 days per week for 6 weeks. A limited number of individualized phrases were trained. Three of 4 boys demonstrated improvement in treated phrases and some generalization to untaught phrases. Baas and colleagues [72] used DTTC principles in the treatment of a 12-year-old boy with CHARGE association (a complex genetic disorder affecting cognitive and speech/language development), severe CAS, mild cognitive impairment, and little verbal communication at study onset. After 25 months of treatment, this multiple baseline across behaviors study demonstrated improved use of a small number of functional verbal utterances. The authors suggested that speech treatment can improve functional verbal communication in older children and that the most important factor for retention was amount of practice. It should be noted that this suggestion was based on findings with only one child.

Recently, the effectiveness of DTTC has been further tested in two 5-year-old sequential Spanish-English bilingual children, one with a moderate-to-severe SSD and one with severe CAS [73•]. In a multiple baseline across behaviors design, DTTC principles were used to treat speech targets that applied to both languages. Both boys improved speech skills in both languages in terms of more accurate speech targets and overall intelligibility measures, supporting the cross-linguistic DTTC approach in a bilingual child with CAS and suggesting these principles can be effective in treatment of other SSDs.

While continued studies are needed to best understand efficient and effective ways to treat CAS, the variety of research studies conducted by different researchers with children of different ages, disorder profiles, and levels of severity suggest the effectiveness of DTTC in addressing motor planning difficulties in the treatment of CAS. Clearly however, further research is needed with larger sample sizes to address the generalizability of these findings, as well as to identify the components or “ingredients” of this approach that are the most important in effecting improvement, including generalization. These studies suggest several factors of potential importance. Across treatment studies, the greatest gains occurred when targets were functional, treatment was frequent, and production frequency and motivation were highest.

Rapid Syllable Transition (ReST)

ReST [19,62••] is an approach that uses practice of varied lexical stress patterns to remediate difficulty with stress assignment that has been identified as a potential diagnostic marker for CAS [6]. This approach is guided explicitly by the motor learning principles reviewed previously, and is based on the idea that repeatedly practicing a variety of multisyllabic nonwords encourages the child to focus on transitioning between syllables, thought to be a core problem in CAS. Nonwords based on sounds in the child’s inventory are used as a surrogate for novel vocabulary acquisition [74] and consist of multiple syllables to facilitate transitions from one movement gesture to the next. Motor learning principles are incorporated by providing a large number of practice trials (ideally, 100 or more total trials) per session [10,11,25,75], by using a random practice schedule with variable practice of complex targets, and by reduced use of feedback. ReST is suggested for use with older children who have mild to moderate speech motor impairment.

Three recent studies specifically examined treatment for prosody. In the first, 3 children with CAS showed improvement in their ability to control the relative duration of syllables in words with strong-weak and weak-strong stress patterns [19]. Following 3 weeks of treatment for 60 minutes 4 days per week, there was generalization to untreated nonwords, but negligible generalization to real words. A study with 14 typically-developing children [76] showed that children could learn to produce target lexical stress in nonwords and that there was maintenance and generalization to untrained nonwords. The third, very recent study was a randomized controlled trial (RCT), involving 13 children with CAS in the ReST group [62••,77], which demonstrated improved speech accuracy of treated and untreated nonwords and words (judged perceptually).

Nuffield Dyspraxia Programme, 3rd Edition (NDP3)

There are a number of CAS treatment programs that have been commercially available for some time despite the absence of controlled studies to support their efficacy. One such program is the Nuffield Dyspraxia Programme, 3rd edition (NDP3) [63,64], widely used in the United Kingdom and Australia. This bottom-up approach builds from single sounds to syllables and syllable sequences. Motor learning principles that facilitate performance are emphasized, such as frequent feedback and blocked practice. This approach includes phonological awareness skills and explicit work on phrasal stress as longer sequences become targets. NDP3 is considered appropriate for children ages 4–12 with mild to severe speech motor impairment (including CAS).

Preliminary uncontrolled case studies examining the NDP3, presented in two unpublished master's theses, showed improved percent consonants correct and intelligibility ratings [78,79]. More recently, the RCT mentioned above [62••,77] compared the NDP3 to ReST (N=13 in each group), and reported significantly improved speech accuracy in treated and untreated nonwords and words in both groups. Thus, this latter study offers the first controlled evidence for effectiveness of this program. Results showed stronger effects for treatment and generalization in both groups than previously reported with the NDP3 [78], which could be attributed to the higher treatment intensity (12 one-hour sessions, four days per week for 3 weeks as compared to 20 sessions conducted for one hour once per week). This RCT also revealed that while children made gains with both types of treatment, there was a stronger maintenance of gains for ReST versus NDP3. The authors postulated that this difference was due to emphasis on different principles of motor learning that would be expected to facilitate retention (ReST) versus those expected to facilitate acquisition/ performance (NDP3).

PROMPT

Physically Restructuring Oral Muscular Phonetic Targets (PROMPT) [80,81**]** is described as a treatment approach that integrates cognitive, linguistic, motor, and sensory aspects of communication. One premise is that a child will be taught to develop motor skills for speaking in the context of interactive language. Tactile cues help the child learn to associate tactile-kinesthetic information with the auditory outcome. The child's overall motor system is considered by providing appropriate positional support, and targets are chosen for their value in enhancing the child's functional communication. Communication "structures" are assembled based on a proposed Motor Speech Treatment Hierarchy [81,82] that begins at a level of general body tone and phonation, moves to a higher level of motor skill involving control of articulators, and considers the greatest levels of complexity to involve production of sequenced movements and the ability to control fundamental vocal frequency, intensity and duration for prosodic variation. These levels are described as interrelated and overlapping [81]. A child's skills are evaluated at each level of the hierarchy to determine at which point treatment should begin. PROMPT is proposed as an appropriate intervention for a range of children, including children who are very young or who have cognitive delay, with speech motor impairment ranging from mild to severe. Speech-language pathologists must be trained and/or certified through the PROMPT Institute to provide PROMPT intervention.

Although PROMPT has been recommended for use with children with CAS for several decades [80], relatively little published controlled evidence exists to support this claim. One case study of PROMPT [83] used kinematic measures to examine articulatory movements of a 3-year-old child with SSD who may have had CAS. The results showed changes both in movement parameters and accuracy ratings following treatment for both trained and untrained words; however, the study design did not include experimental control measures, making it difficult to ascribe the improvement to the treatment. Another recent study [81] compared progress for treatment targets taught with and without tactile cues in 4 children with CAS. Improved accuracy was documented for all children on both trained and untrained targets. The authors reported greater progress when the tactile cues were used, although the differences were small and confounded with order effects. The authors suggested that characteristics of an individual child will have implications for their response to intervention. For example, a recent study suggests that sensory integration difficulties may influence the efficacy of speech therapy in children with articulation disorders [84].

Another recent study [85] examined cortical thickness in 12 children with CAS before and after PROMPT treatment. The study reported improvements on all speech measures; however, the study design did not include experimental control measures (essentially a one-group pre-post design), and as such it cannot be concluded that any improvements were attributable to the intervention. A number of additional studies have examined PROMPT intervention in children with motor speech disorders, with sample sizes ranging from N=5 to N=12, although all of these studies explicitly excluded children with CAS [86–88]. Further, only one of these studies [87] used a design with experimental control measures, rather than uncontrolled pre-post designs which cannot support claims of efficacy. It should also be noted that all these studies were conducted by the same research group, affiliated with the PROMPT Institute.

Biofeedback Treatment

Given suggestions that CAS involves a deficit in auditory and/or somatosensory feedback processing [89–91] and some indication for impaired auditory perception in CAS [92,93], several recent CAS treatment studies aimed to enhance treatment by supplementing auditory and verbal feedback with visual feedback [94,95•]. The rationale is that children with CAS may utilize feedback provided through a different modality to improve their speech movements. Lundeborg and McAllister [94] used electropalatography with one child with CAS to provide visual information about tongue-to-palate contact patterns in the context of an intra-oral sensory stimulation and articulation treatment with various lingual sound (and nonsound) targets. Although the child demonstrated improved speech accuracy, the intervention design (uncontrolled pre-post design) prevents conclusions as to whether the biofeedback was responsible for these gains.

More recently, Preston et al. [95] reported a treatment study using a multiple baselines across behaviors design for 6 children with CAS using real-time ultrasound images of the tongue as biofeedback. Treatment focused on individualized sound and sound sequence targets. All children demonstrated gains on at least two of their targets, and gains were largely maintained at the 2-month follow-up. These findings are promising, and consistent with application of biofeedback treatments in other populations [46,50–52,96–98]. Much research remains to be done regarding biofeedback treatment for CAS: younger children may not benefit from biofeedback [52] and the use of acoustic spectral biofeedback [52,97] has not yet been explored in this population.

Summary

Overall, the available evidence suggests that children with CAS can improve their speech motor skills with a variety of motor-based intervention protocols. Most of these approaches combine a number of ingredients that are likely to contribute to the improvements. These ingredients, shared by many if not all approaches, include a high amount of practice, a relatively small set of treatment targets, a homework component, provision of knowledge of results and knowledge of performance feedback, and use of alternative feedback modalities (e.g., visual feedback, tactile cues). There are also many differences between approaches, for example in terms of target selection criteria, distribution of practice, elicitation method, frequency of feedback, and practice schedule. It is clear that further research is needed to identify the optimal conditions and ingredients to achieve maximal improvements in children with CAS.

The evidence base for specific treatment approaches varies. For example, the integral stimulation approach currently has the strongest evidence base in the sense that this approach has been shown to be effective in six studies using controlled single-case experimental designs, conducted in three independent labs. ReST has fewer studies to support it, all of which produced by the same research group, but its evidence includes an RCT, which qualifies as a higher level of evidence [99]. The evidence base for NDP3 includes two unpublished uncontrolled case studies and one recent RCT, conducted by a research group unaffiliated with the NDP3. PROMPT has been investigated in a number of studies, though most of these either explicitly excluded children with CAS and/or did not include proper controls to support claims of efficacy, and all these studies were conducted by researchers affiliated with the PROMPT Institute.

CONCLUSION

In this paper we reviewed several recent trends in motor-based treatments for CAS. Perhaps most importantly, while the current evidence-base remains relatively small, there is a trend toward more treatment efficacy studies, with increasingly rigorous experimental designs, although there is clearly room for further improvement in the quality of the designs. The trend for increasingly rigorous experimental designs is encouraging, and includes well-controlled single-case experimental designs [14••,19–22•], as well a recent RCT [62••,77], the first in this area. While single-case experimental designs and RCTs each have their strengths and limitations, one obvious advantage of RCTs over single-case experimental designs (in addition to facilitating treatment comparisons) is the ability to explore child variables that may predict efficacy of a particular approach for a particular child. Ultimately we need to understand the inter-individual variability in response to treatment, so that clinicians can devise the most appropriate intervention for their individual clients.

The findings to date show that motor-based interventions can produce gains in speech production abilities in children with CAS [100••]. At present, a DTTC-type integral stimulation approach has the strongest evidence base, with replicated evidence of efficacy from several well-controlled single-case experimental design studies from different, independent research groups. Evidence in support of other approaches, including the use of biofeedback, is beginning to emerge, which means that comparative treatment studies are now also warranted [62••,77].

Another relatively recent trend is the use of motor learning principles in treatment for CAS. While the limited evidence to date is encouraging, not all children respond to a given practice condition manipulation in the same way, both within and across studies. Nevertheless, the concepts and motor learning principles provide a useful framework for exploring optimal intervention conditions. For example, one relevant variable for explaining across-study differences is practice distribution. Target selection criteria (e.g., based on functional relevance vs. specific sound sequences) and dosage are also likely to be important.

Overall, current developments in the area of CAS treatment will likely make significant contributions to optimize intervention protocols and clinical decision-making for individual clients. We expect to see a continuation and expansion of these developments over the next years.

References

Papers of particular interest, published recently, have been highlighted as:

• Of importance

•• Of major importance

1. Shriberg LD. Four new speech and prosody-voice measures for genetics research and other studies in developmental phonological disorders. Journal of Speech and Hearing Research. 1993; 36:105–140. [PubMed: 8450654]

2. Shriberg LD. Five subtypes of developmental phonological disorders. Clinics in Communication Disorders. 1994; 4:38–53. [PubMed: 8019550]

3. Shriberg LD, Austin D, Lewis BA, McSweeny JL, Wilson DL. The Speech Disorders Classification System (SDCS): Extensions and lifespan reference data. Journal of Speech, Language, and Hearing Research. 1997; 40:723–740.

4. Pannbacker M. Management strategies for developmental apraxia of speech: A review of literature. Journal of Communication Disorders. 1988; 21:363–371. [PubMed: 3053798]

5••. Shriberg LD, Lohmeier HL, Strand EA, Jakielski KJ. Encoding, memory, and transcoding deficits in Childhood Apraxia of Speech. Clinical Linguistics and Phonetics. 2012; 26:445–482. This paper is of major importance because it presents the most comprehensive data to date regarding the underlying nature of speech impairments in children with childhood apraxia of speech compared to children with non-CAS speech sound disorder. [PubMed: 22489736]

6. American Speech-Language-Hearing Association. Childhood Apraxia of Speech. Technical Report. 2007 Mar. Retrieved from http://www.asha.org/policy2011

7. McNeill BC, Gillon GT, Dodd B. Effectiveness of an integrated phonological awareness approach for children with childhood apraxia of speech. Child Language Teaching and Therapy. 2009; 25:341–366.

8. Campbell, TF. Functional treatment outcomes in young children with motor speech disorders. In: Caruso, AJ.; Strand, EA., editors. Clinical Management of Motor Speech Disorders in Children. New York: Thieme; 1999. p. 385-396.

9. Shriberg LD, Aram DM, Kwiatkowski J. Developmental apraxia of speech: I. Descriptive and theoretical perspectives. Journal of Speech, Language, and Hearing Research. 1997; 40:273–285.

10. Schmidt, RA.; Lee, TD. Motor Control and Learning: A Behavioral Emphasis. 4. Champaign, IL: Human Kinetics; 2005.

11. Maas E, Robin DA, Austermann Hula SN, Freedman SE, Wulf G, Ballard KJ, Schmidt RA. Principles of motor learning in treatment of motor speech disorders. American Journal of Speech-Language Pathology. 2008; 17:277–298. [PubMed: 18663111]

12. Strand EA, Stoeckel R, Baas B. Treatment of severe childhood apraxia of speech: A treatment efficacy study. Journal of Medical Speech-Language Pathology. 2006; 14:297–307.

13. Davis BL, Velleman SL. Differential diagnosis and treatment of developmental apraxia of speech in infants and toddlers. Infant-Toddler Intervention. 2000; 10(3):177–192.

14••. Edeal DM, Gildersleeve-Neumann CE. The importance of production frequency in therapy for childhood apraxia of speech. American Journal of Speech-Language Pathology. 2011; 20:95–110. This paper is of major importance because it was the first treatment study to examine a specific motor learning principle in treatment for CAS. The study demonstrated that children with CAS show greater learning with more practice opportunities. [PubMed: 21330650]

15. Hall PK. A letter to the parent(s) of a child with developmental apraxia of speech. Part IV: Treatment of DAS. Language, Speech, and Hearing Services in Schools. 2000; 31:179–181.

16. Iuzzini J, Forrest K. Evaluation of a combined treatment approach for childhood apraxia of speech. Clinical Linguistics & Phonetics. 2010; 24(4–5):335–345. [PubMed: 20345262]

17. McCauley, RJ.; Strand, EA. Treatment of children exhibiting phonological disorder with motor speech involvement. In: Strand, EA.; Caruso, AJ., editors. Clinical Management of Motor Speech Disorders in Children. New York: Thieme; 1999. p. 187-208.

18. Robin, DA.; Maas, E.; Sandberg, Y.; Schmidt, RA. Motor control and learning and childhood apraxia of speech. In: Hall, P.; Jordan, L.; Robin, D., editors. Developmental Apraxia of Speech: Theory and Clinical Practice. 2. Austin, TX: Pro-Ed; 2007.

19. Ballard KJ, Robin DA, McCabe P, McDonald J. A treatment for dysprosody in childhood apraxia of speech. Journal of Speech, Language, and Hearing Research. 2010; 53:1227–1245.

20. Strand EA, Debertine P. The efficacy of integral stimulation intervention with developmental apraxia of speech. Journal of Medical Speech-Language Pathology. 2000; 8:295–300.

21. Maas E, Butalla CE, Farinella KA. Feedback frequency in treatment for childhood apraxia of speech. American Journal of Speech-Language Pathology. 2012; 21:239–257. [PubMed: 22442284]

22•. Maas E, Farinella KA. Random versus blocked practice in treatment for childhood apraxia of speech. Journal of Speech, Language, and Hearing Research. 2012; 55:561–578. This paper is of importance because it demonstrated that although motor learning principles may influence speech motor learning in children with CAS, these effects may differ across children. As such, this paper highlights the need to conduct direct empirical study of motor learning principles in the population of interest.

23. Schmidt RA. A schema theory of discrete motor skill learning. Psychological Review. 1975; 82:225–260.

24. Kelso JAS, Zanone PG. Coordination dynamics of learning and transfer across different effector systems. Journal of Experimental Psychology: Human Perception and Performance. 2002; 28:776–797. [PubMed: 12190250]

25. Buchanan JJ, Zihlman K, Ryu YU, Wright DL. Learning and transfer of a relative phase pattern and a joint amplitude ratio in a rhythmic multijoint arm movement. Journal of Motor Behavior. 2007; 39:49–67. [PubMed: 17251171]

26. Namasivayam AK, van Lieshout P. Investigating speech motor practice and learning in people who stutter. Journal of Fluency Disorders. 2008; 33:32–51. [PubMed: 18280868]

27. Ryu YU, Buchanan JJ. Learning an environment-actor coordination skill: visuomotor transformation and coherency of perceptual structure. Experimental Brain Research. 2009; 196:279–293b. [PubMed: 19466397]
28. Bruechert L, Lai Q, Shea CH. Reduced knowledge of results frequency enhances error detection. Research Quarterly for Exercise and Sport. 2003; 74(4):467–472. [PubMed: 14768847]
29. Winstein CJ, Schmidt RA. Reduced frequency of knowledge of results enhances motor skill learning. Journal of Experimental Psychology: Learning, Memory, and Cognition. 1990; 16:677–691.
30. Bislick LP, Weir PC, Spencer K, Kendall D, Yorkston KM. Do principles of motor learning enhance retention and transfer of speech skills? A systematic review. Aphasiology. 2012; 26:709–728.
31. Skelton SL, Funk TE. Teaching speech sounds to young children using randomly ordered, variably complex task sequences. Perceptual and Motor Skills. 2004; 99:602–604. [PubMed: 15560350]
32. Lasker JP, Stierwalt JAG, Hageman CF, LaPointe LL. Using motor learning guided theory and augmentative and alternative communication to improve speech production in profound apraxia: A case example. Journal of Medical Speech-Language Pathology. 2008; 16:225–233.
33. Adams SG, Page AD. Effects of selected practice and feedback variables on speech motor learning. Journal of Medical Speech-Language Pathology. 2000; 8:215–220.
34. Scheiner, L.; Sadagopan, N.; Sherwood, D. The effect of practice schedules on short- and longer-term nonword acquisition and retention. Poster presented at the 16th Biennial Conference on Motor Speech; Santa Rosa, CA. March 2012; 2012.
35. Wong AWK, Whitehill TL, Ma EPM, Masters R. Effects of practice schedules on speech motor learning. International Journal of Speech-Language Pathology. 2013; 15:511–523. [PubMed: 23374024]
36. Kim I, LaPointe LL, Stierwalt JAG. The effect of feedback and practice on the acquisition of novel speech behaviors. American Journal of Speech-Language Pathology. 2012; 21:89–100. [PubMed: 22230183]
37. Ballard KJ, Smith HD, Paramatmuni D, McCabe P, Theodoros DG, Murdoch BE. Amount of kinematic feedback affects learning of speech motor skills. Motor Control. 2012; 16:106–119. [PubMed: 22402216]
38. Steinhauer K, Grayhack JP. The role of knowledge of results in performance and learning of a voice motor task. Journal of Voice. 2000; 14:137–145. [PubMed: 10875564]
39. Ma EPM, Yiu GKY, Yiu EML. The effects of self-controlled feedback on learning of a “relaxed phonation task”. Journal of Voice. 2013; 27:723–728. [PubMed: 24075527]
40. Lisman AL, Sadagopan N. Focus of attention and speech motor performance. Journal of Communication Disorders. 2013; 46:281–293. [PubMed: 23497961]
41. Knock T, Ballard KJ, Robin DA, Schmidt RA. Influence of order of stimulus presentation on speech motor learning: A principled approach to treatment for apraxia of speech. Aphasiology. 2000; 14:653–668.
42. Wambaugh JL, Nessler C, Cameron R, Mauszycki SC. Treatment for acquired apraxia of speech: Examination of treatment intensity and practice schedule. American Journal of Speech-Language Pathology. 2013; 22:84–102. [PubMed: 23071199]
43. Wong AYH, Ma EPM, Yiu EML. Effects of practice variability on learning of relaxed phonation in vocally hyperfunctional speakers. Journal of Voice. 2011; 25:e103–e113. [PubMed: 20456910]
44. Allen MM. Intervention efficacy and intensity for children with speech sound disorder. Journal of Speech, Language, and Hearing Research. 2013; 56:865–877.
45. Spielman J, Ramig LO, Mahler L, Halpern A, Gavin WJ. Effects of an extended version of the Lee Silverman Voice Treatment on voice and speech in Parkinson’s disease. American Journal of Speech-Language Pathology. 2007; 16:95–107. [PubMed: 17456888]
46. Katz WF, Bharadwaj SV, Carstens B. Electromagnetic articulography treatment for an adult with Broca’s aphasia and apraxia of speech. Journal of Speech, Language, and Hearing Research. 1999; 42:1355–1366.
47. Adams SG, Page AD, Jog MS. Summary feedback schedules and speech motor learning in Parkinson’s disease. Journal of Medical Speech-Language Pathology. 2002; 10:215–220.

48. Austermann Hula SN, Robin DA, Maas E, Ballard KJ, Schmidt RA. Effects of feedback frequency and timing on acquisition, retention, and transfer of speech skills in acquired apraxia of speech. Journal of Speech, Language, and Hearing Research. 2008; 51:1088–1113.
49. Bislick LP, Weir PC, Spencer KA. Investigation of feedback schedules on speech motor learning in individuals with apraxia of speech. Journal of Medical Speech-Language Pathology. 2013; 20:18–23.
50. Katz WF, McNeil MR, Garst DM. Treating apraxia of speech (AOS) with EMA-supplied visual augmented feedback. Aphasiology. 2010; 24:826–837.
51. McNeil MR, Katz WF, Fossett TRD, Garst DM, Szuminsky NJ, Carter G, Lim KY. Effects of online augmented kinematic and perceptual feedback on treatment of speech movements in apraxia of speech. Folia Phoniatrica et Logopaedica. 2010; 62:127–133. [PubMed: 20424468]
52. McAllister Byun, T.; Maas, E.; Swartz, MT. Motor learning principles in/r/treatment: Direction of attentional focus. Paper presented to the American Speech-Language-Hearing Association Convention; Chicago, IL. November 2013; 2013.
53. Park JH, Shea CH. Sequence learning: Response structure and effector transfer. Quarterly Journal of Experimental Psychology. 2005; 58A:387–419. [PubMed: 16025755]
54. Shea CH, Kohl RM, Indermill C. Contextual interference: Contributions of practice. Acta Psychologica. 1990; 73:145–157.
55. Wright DL, Black CB, Immink MA, Brueckner S, Magnuson C. Long-term motor programming improvements occur via concatenating movement sequences during random but not blocked practice. Journal of Motor Behavior. 2004; 36:39–50. [PubMed: 14766487]
56. Sullivan KJ, Kantak SS, Burtner PA. Motor learning in children: Feedback effects on skill acquisition. Physical Therapy. 2008; 88(6):720–732. [PubMed: 18339797]
57. Wulf G, Shea CH, Matschiner S. Frequent feedback enhances complex motor skill learning. Journal of Motor Behavior. 1998; 30(2):180–192. [PubMed: 20037033]
58. Wulf G, Shea CH. Principles derived from the study of simple motor skills do not generalize to complex skill learning. Psychonomic Bulletin and Review. 2002; 9:185–211. [PubMed: 12120783]
59. Shea CH, Lai Q, Black C, Park JH. Spacing practice sessions across days benefits the learning of motor skills. Human Movement Science. 2000; 19:737–760.
60. Shriberg, LD.; Strand, EA.; Jakielski, KJ. Diagnostic signs of childhood apraxia of speech in idiopathic, neurogenetic, and complex neurodevelopmental contexts. Paper presented at the Sixteenth Biennial Conference on Motor Speech; Santa Rosa, CA. 2010 Feb-Mar.
61. Schmidt, RA.; Wrisberg, CA. Motor learning and performance: A problem-based learning approach. 3. Champaign, IL: Human Kinetics; 2004.
62••. Murray E, McCabe P, Ballard KJ. A comparison of two treatments for childhood apraxia of speech: methods and treatment protocol for a parallel group randomized control trial. BMC Pediatrics. 2012; 12:112. This paper is of major importance because it represents the first reported randomized controlled trial for treatment of CAS. This paper presents the protocol of the study, which compares two different treatment programs. [PubMed: 22863021]
63. Williams, P.; Stephens, H. Nuffield Dyspraxia Programme. 3. Windsor, England: The Miracle Factory; 2004.
64. Williams, P.; Stephens, H. The Nuffield Centre Dyspraxia Programme. In: Williams, AL.; McLeod, S.; McCauley, RJ., editors. Interventions for speech sound disorders in children. Baltimore, MD: Paul H. Brookes; 2010. p. 159-177.
65. Rochet-Capellan A, Richer L, Ostry DJ. Nonhomogeneous transfer reveals specificity in speech motor learning. Journal of Neurophysiology. 2012; 107:1711–1717. [PubMed: 22190628]
66. Clark HM. Neuromuscular treatments for speech and swallowing: A tutorial. American Journal of Speech-Language Pathology. 2003; 12:400–415. [PubMed: 14658992]
67. Maas E, Barlow J, Robin D, Shapiro L. Treatment of sound errors in aphasia and apraxia of speech: Effects of phonological complexity. Aphasiology. 2002; 16:609–622. [PubMed: 22787286]
68. Schneider SL, Frens RA. Training four-syllable CV patterns in individuals with acquired apraxia of speech: Theoretical implications. Aphasiology. 2005; 19:451–471.

69. Gierut JA. Complexity in phonological treatment: Clinical factors. Language, Speech, and Hearing Services in Schools. 2001; 32:229–241.

70. Baker, E.; Williams, AL. Complexity approaches to intervention. In: Williams, AL.; McLeod, S.; McCauley, RJ., editors. Interventions for speech sound disorders in children. Baltimore, MD: Paul H. Brookes; 2010. p. 95-115.

71. Rosenbek JC, Lemme ML, Ahern MB, Harris EH, Wertz RT. A treatment for apraxia of speech in adults. Journal of Speech and Hearing Disorders. 1973; 38:462–472. [PubMed: 4754879]

72. Baas BS, Strand EA, Elmer LM, Barbaresi WJ. Treatment of severe childhood apraxia of speech in a 12-year-old male with CHARGE association. Journal of Medical Speech-Language Pathology. 2008; 16:181–190.

73•. Gildersleeve-Neumann CE, Goldstein BA. Cross-linguistic generalization in the treatment of two sequential Spanish-English bilingual children with speech sound disorders. International Journal of Speech-Language Pathology. 2014 In press. This paper is of importance because it is the first study to report the efficacy of integral stimulation treatment in bilingual children with speech sound disorders.

74. Gierut JA, Morrisette ML, Ziemer SM. Nonwords and generalization in children with phonological disorders. American Journal of Speech-Language Pathology. 2010; 19:167–177. [PubMed: 20086043]

75. Wulf G, Shea C, Lewthwaite R. Motor skill learning and performance: a review of influential factors. Medical Education. 2010; 44:75–84. [PubMed: 20078758]

76. van Rees LJ, Ballard KJ, McCabe P, Macdonald-D'Silva AG, Arciuli J. Training production of lexical stress in typically developing children with orthographically biased stimuli and principles of motor learning. American Journal of Speech-Language Pathology. 2012; 21:197–206. [PubMed: 22411774]

77. Murray, E.; McCabe, P.; Ballard, KJ. Exploring factors that determined treatment success: data from a randomized control trial for childhood apraxia of speech. Paper presented at the American Speech-Language-Hearing Association Convention; November; Chicago, IL. 2013.

78. Belton, E. Unpublished MSc thesis. University College; London: 2006. Evaluation of the Effectiveness of the Nuffield Dyspraxia Programme as a treatment approach for children with severe speech disorders.

79. Teal, J. An investigation into classification approaches and therapy outcomes for a child with a severe persisteing speech difficulty. University of Sheffield; Sheffield: 2005.

80. Chumpelik D. The PROMPT system of therapy: Theoretical framework and applications for developmental apraxia of speech. Seminars in Speech and Language. 1984; 5:139–156.

81. Dale PS, Hayden DA. Treating speech subsystems in childhood apraxia of speech with tactual input: The PROMPT approach. American Journal of Speech-Language Pathology. 2013; 22:644–661. [PubMed: 23813194]

82. Hayden DA, Square PA. Motor speech treatment hierarchy: A systems approach. Clinics in Communication Disorders. 1994; 4:162–174. [PubMed: 7994291]

83. Grigos M, Hayden D, Eigen J. Perceptual and articulatory changes in speech production following PROMPT treatment. Journal of Medical Speech-Language Pathology. 2010; 18:46–53. [PubMed: 22984339]

84. Tung LC, Lin CK, Hsieh CL, Chen CC, Huang CT, Wang CH. Sensory integration dysfunction affects efficacy of speech therapy on children with functional articulation disorders. Neuropsychiatric Disease and Treatment. 2013; 9:87–92. [PubMed: 23355780]

85. Kadis DS, Goshulak D, Namasivayam A, Pukonen M, Kroll R, de Nil LF, Pang EW, Perch JP. Cortical thickness in children receiving intensive therapy for idiopathic apraxia of speech. Brain Topography. 2013 (in press).

86. Namasivayam AK, Pukonen M, Goshulak D, Yu VY, Kadis DS, Kroll R, Pang EW, De Nil LF. Relationship between speech motor control and speech intelligibility in children with speech sound disorders. Journal of Communication Disorders. 2013; 46:264–80. [PubMed: 23628222]

87. Square PA, Namasivayam AK, Bose A, Goshulak D, Hayden D. Multi-sensory treatment for children with developmental motor speech disorders. International Journal of Language and Communication Disorders. 2014 (in press).

88. Yu VY, Kadis DS, Oh A, Goshulak D, Namasivayam A, Pukonen M, Kroll R, de Nil LF, Wang EW. Changes in voice onset time and motor speech skills in children following motor speech therapy: Evidence from/pa/productions. Clinical Linguistics & Phonetics. 2014 (in press).

89. Terband H, Maassen B. Speech motor development in childhood apraxia of speech: Generating testable hypotheses by neurocomputational modeling. Folia Phoniatrica et Logopaedica. 2010; 62:134–142. [PubMed: 20424469]

90. Terband H, Maassen B, Guenther FH, Brumberg J. Computational neural modeling of speech motor control in childhood apraxia of speech (CAS). Journal of Speech, Language, and Hearing Research. 2009; 52:1595–1609.

91. Terband, H.; Maassen, B.; Guenther, FH.; Brumberg, J. Auditory-motor interactions in pediatric motor speech disorders: Neurocomputational modeling of disordered development. Journal of Communication Disorders. 2014. In press. http://dx.doi.org/10.1016/j.jcomdis.2014.01.001

92. Groenen P, Maassen B, Crul T, Thoonen G. The specific relation between perception and production errors for place of articulation in developmental apraxia of speech. Journal of Speech and Hearing Research. 1996; 39:468–482. [PubMed: 8783127]

93. Nijland L. Speech perception in children with speech output disorders. Clinical Linguistics & Phonetics. 2009; 23:222–239. [PubMed: 19283579]

94. Lundeborg I, McAllister A. Treatment with a combination of intra-oral sensory stimulation and electropalatography in a child with severe developmental dyspraxia. Logopedics Phoniatrics Vocology. 2007; 32:71–79.

95•. Preston JL, Brick N, Landi N. Ultrasound biofeedback treatment for persisting childhood apraxia of speech. American Journal of Speech-Language Pathology. 2013; 22:627–643. This paper is of importance because it is the first demonstration of the efficacy of visual ultrasound biofeedback in the treatment of older children with CAS. [PubMed: 23813207]

96. Preston JL, Leaman M. Ultrasound visual feedback for acquired apraxia of speech: A case report. Aphasiology. 2014; 28:278–295.

97. McAllister Byun T, Hitchcock ER. Investigating the use of traditional and spectral biofeedback approaches to intervention for/r/misarticulation. American Journal of Speech-Language Pathology. 2012; 21:207–221. [PubMed: 22442281]

98. Shuster LI, Ruscello DM, Toth AR. The use of visual feedback to elicit correct/r/. American Journal of Speech-Language Pathology. 1995; 4:37–44.

99. American Speech-Language-Hearing Association. Evidence-Based Practice in Communication Disorders: An Introduction. Technical report. 2004. Available at: http://www.asha.org/members/deskref-journals/deskref/default

100••. Murray E, McCabe P, Ballard KJ. A systematic review of treatment outcomes for children with Childhood Apraxia of Speech. American Journal of Speech-Language Pathology. (in press). This paper is of major importance because it presents the first systematic review of the CAS treatment literature that takes into account both group studies and single-case experimental design studies.