

# Motor-Based Intervention Protocols in Treatment of Childhood Apraxia of Speech (CAS)

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**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, which is followed by a discussion of the potential relevance of principles derived from the motor learning literature for CAS treatment. Next, various motor-based treatment protocols are reviewed, along with their evidence base. The paper concludes with a summary and discussion of future research needs.

**Keywords** Childhood apraxia of speech · Treatment · Speech motor control · Speech motor learning · Speech disorders

## Introduction

Speech sound disorders (SSD) have historically 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 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 to 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 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. To a lesser extent, individuals with CAS may demonstrate difficulties with forming, storing, and retrieving representations of auditory/perceptual information [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••]. An estimated 3–5 % of children diagnosed with SSD exhibit the CAS subtype [2]. In this article, we discuss interventions specifically for CAS, with an emphasis on motor-based interventions, and we do not discuss

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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 we 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 with extraordinary spatiotemporal demands, requiring coordination across many different muscle groups. 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 treatment periods [8, 9]. Given the challenges in many clinical settings (e.g., high caseloads, limited third-party reimbursements), maximum utilization of limited resources is imperative.

The motor skill learning literature is a promising resource for optimizing treatment. A number of conditions have been found to facilitate learning (retention and transfer) of motor skills [10]. These relatively predictable advantages of certain conditions over others (e.g., more practice facilitates learning compared to less practice) are sometimes referred to as *motor learning principles* [11, 12]. Over the past 15 years, the incorporation of motor learning principles into treatment for CAS has been recommended [12, 13, 14•, 15–18]. 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—although by no means all—of this literature has been inspired by the schema theory of motor control and learning [10, 23], and this 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 Dynamic Systems Theory [24]. To date, however, this 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 of which indicate 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 have reported findings consistent with the motor learning literature [14•, 41, 47], others have failed to find clear and consistent differences between conditions [42, 43, 45, 51, 52] or have 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 directly examined conditions of practice and feedback [14•, 21, 22•]. All three used a single-case experimental (alternating treatments) design. Edeal and Gildersleeve-Neumann [14•] examined practice amount for two 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 (30–40 trials per session) condition. 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 four 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 two 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 four children with CAS. While two 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 once again mixed, indicating that more research is needed to specifically investigate 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 non-speech 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, as 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], despite its potential clinical relevance, has not yet been studied in this population. 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 six weeks, whereas Maas and colleagues [21, 22•] found relatively modest effects when providing modified DTTC treatment three times per week over eight weeks (overall treatment approximately 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 to 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 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. Types of targets should be selected 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 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 stimutable 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, 21, 22•, 62••, 63, 64], each approach may focus on different targets. For example, DTTC [12, 20] targets primarily functional words and phrases, although nothing in the approach precludes targeting other speech elements (e.g., syllables, words). In Rapid Syllable Transition (ReST) [62••], strings of non-sense 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 may be appropriate because, after they are learned, the child could use these exact words in different contexts. However, selecting non-word targets may 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 non-word targets depends on a child's ability to generalize improved skills learned in the context of non-word forms to real words, which 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, 21, 22•], research on ReST is documenting generalization from non-word targets [19]. The principle of task specificity, however, 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. While it is difficult to determine and measure speech complexity [11], and there are multiple interpretations of it [40, 67, 68], clinical decisions regarding basic versus complex speech targets are typically made by considering production aspects such as place and manner features and phonotactic structure. Three CAS-specific intervention approaches [12, 20, 62••, 63, 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 that treatment for CAS is 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, and 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 single-case experimental design studies demonstrating improvement in speech production in individual children [12, 14••, 20, 21, 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 based on the child's response and motivation [20, 71]. Cues can vary from 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, the rate is slowly increased to conversational rates.

While DTTC is hierarchical in that supports are reduced 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].

The effectiveness of DTTC 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 four days a week in intensive 30-minute blocks for 33 sessions. Speech accuracy (as judged perceptually by the clinician) of targeted functional phrases increased, although 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, five days per week, for six weeks. A limited number of individualized phrases were trained. Three of the four 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-baselines-across-behaviors study demonstrated improved use of a small number of functional verbal utterances. The authors suggested that speech treatment could improve functional verbal communication in older children and that the most important factor for retention was the amount of practice. It should be noted that this suggestion was based on findings with only one child.

The effectiveness of DTTC was recently 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-baselines-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 that 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 non-words encourages the child to focus on transitioning between syllables, which is thought to be a core problem in CAS. Non-words 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, three 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 three weeks of treatment with 60-minute sessions four days per week, there was generalization to untreated non-words, 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 non-words and that there was maintenance and generalization to untrained non-words. 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 non-words and words (judged perceptually).

#### Nuffield Dyspraxia Programme, 3rd Edition (NDP3)

Despite the absence of controlled studies to support their efficacy, there are a number of CAS treatment programs that have been commercially available for some time. 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, such as frequent feedback and blocked practice, are emphasized. 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 non-words and words in both groups. This latter study thus 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 may be attributable to the higher treatment intensity (12 one-hour sessions, four days per week for three weeks as compared to 20 one-hour sessions once per week). This RCT also revealed that while children made gains with both types of treatment, there was stronger maintenance of gains for ReST versus NDP3. The authors postulated that the 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 upon 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 several decades for use with children with CAS [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. While the results showed changes both in movement parameters and accuracy ratings following treatment for both trained and untrained words, 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 four 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 would 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. Although the study reported improvements on all speech measures, 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 that cannot support claims of efficacy. It should also be noted that all of 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 have 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 non-sound) targets. Although the child demonstrated

improved speech accuracy, the intervention design (uncontrolled pre-post design) precludes 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 six 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 two-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, of the 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 among 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 varies for specific treatment approaches. 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 were 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, although most of these explicitly excluded children with CAS and/or did not include proper controls to support claims of efficacy, and all of the studies were conducted by researchers affiliated with the PROMPT Institute.

### Conclusions

In this paper we reviewed several recent trends in motor-based treatments for CAS. Perhaps most important is that 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 design quality. The trend for increasingly rigorous experimental designs is encouraging, and includes well-controlled single-case experimental designs [14•, 19–21, 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.

To date, the findings indicate that motor-based interventions can produce gains in speech production abilities in children with CAS [100•]. At this time, 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.

### Compliance with Ethics Guidelines

**Conflict of Interest** Edwin Maas has received grants from the National Institute on Deafness and Other Communication Disorders during conduct of the study, personal fees from the Childhood Apraxia of Speech Association of North America, and 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.

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